Full One-Loop Electroweak Corrections to the Charged Higgs Decays into a Chargino and Neutralino in the MSSM

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Abstract

We calculate the full one-loop electroweak (FEW) corrections to $H^- \to \widetilde{\chi}_1^- \widetilde{\chi}_i^0$ in the minimal supersymmetric standard model (MSSM), and compare with the leading order (LO) corrections including the loops of the (s)quarks only in the third generation and the complete leading order (CLO) corrections including the loops of the (s)quarks in all the three generations. We find that the magnitudes of the FEW corrections can be larger than 10% for $\tan\beta > 30$. Moreover, comparing with the FEW corrections, both of the LO and the CLO corrections are negligible small for the mode 1($H^- \to \widetilde{\chi}_1^- \widetilde{\chi}_1^0$) when $\tan\beta < 5$, and for the mode 2($H^- \to \widetilde{\chi}_1^- \widetilde{\chi}_2^0$) when $\tan\beta > 45$, respectively, since there are not enhancements from the Yukawa couplings. We also calculate the FEW corrections in the minimal supergravity (mSUGRA) scenario, where the FEW corrections can be larger than the LO and the CLO corrections by more than 60% and 50%, respectively.

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1 Introduction

Beyond the standard model(SM), the supersymmetric(SUSY) [1] extensions of the SM provide a great opportunity to solve some mysterious problems in the SM. The SUSY partners of the SM particles cancel the quadratic divergences in the corrections to the Higgs boson mass, and the hierarchy problem can be solved naturally. If we consider the R-parity conservation as the essential condition, the lightest SUSY particles(LSP) will never decay, and the stability of the LSP provides the most important candidate for the dark matter [2]. The most attractive extension of the SM is the minimal supersymmetric standard model(MSSM) [3]. If we set all the parameters as real in the MSSM, there will be five Higgs bosons [4]: two CP even bosons (H^0, h^0), one CP odd boson (A^0), and two charged bosons ($H^{\pm}$). When the Higgs boson of the SM has a mass below 130-140 Gev and the h^0 of the MSSM are in the decoupling limit (which means that $H^{\pm}$ is too heavy anyway to be possibly produced), the lightest neutral Higgs boson may be difficult to be distinguished from the neutral Higgs boson of the SM. But the charged Higgs bosons carry a distinctive signature of the Higgs sector in the MSSM. Therefore, the search for the charged Higgs bosons is very important for probing the Higgs sector of the MSSM, and will be one of the prime objectives of the CERN Large Hadron Collider(LHC) [5, 6].

Current bounds on charged Higgs mass can be obtained at the Tevatron, by studying the top decay $t \to bH^+$, which already eliminates some region of parameter space [7], whereas the combined LEP experiments gives a low bounds approximately $m_{H^+} > 78.6$GeV at 95%CL [8]. In the MSSM, we have $m_{H^\pm} \geq 120$ GeV from the mass bounds from LEP–II for the neutral pseudoscalar A^0 of the MSSM ($m_{A^0} \geq 91.9$ GeV) [9].

If the charged Higgs masses could be large enough, there will be many SM and SUSY decay modes. In the MSSM the channels of decay into neutralino and the chargino($H^\pm \to \widetilde{\chi}_i^0 \widetilde{\chi}_j^\pm$) are very important [10], which have been discussed in the Ref. [11], where only the LO corrections were calculated. The one loop corrected effective lagrangian for the charged higgs-neutralino-chargino couplings is calculated in Ref. [12]. In this paper, we present the calculations of the FEW corrections, which include the contributions of the one-loop virtual contributions of the (s)leptons and (s)quarks of all the three generations, and all the possible Higgs and gauge

bosons, charginos and neutralinos and the real corrections i.e. the real photon emission. In the preparation of this paper, a relevant work was given in the Ref. [13] as a conference's short report, which doesn't show any detail of the calculation and the numerical results are not complete.

In Sec.2 we define the relevant notations and show the tree-level result. In Sec.3 we present the virtual corrections, including the vertex corrections and the counterterms. In Sec.4 we illustrate the real corrections from the real photon emission using the phase space slicing(PSS) method [15]. In Sec.5 we present the numerical results and conclusion in the low-energy MSSM and the mSUGRA breaking scenario [16].

2 Notations and Tree-level Width

In order to make this paper self-contained, we first present the relevant interaction Lagrangian [11] of the MSSM and the tree level decay width for $H^+\widetilde{\chi}_i^-\widetilde{\chi}_j^0$ $(i=1,2, \quad j=1,2,3,4)$. The Lagrangian is

$$\mathcal{L}_{H^+\widetilde{\chi}_j^-\widetilde{\chi}_i^0} = -H^+\overline{\widetilde{\chi}_i^0}\left(C_{ij}^L P_L + C_{ij}^R P_R\right)\widetilde{\chi}_j^- + H.c.\,, \tag{1}$$

where,

$$P_{L,R} = \frac{1}{2}(1 \mp \gamma_5),$$

$$\begin{aligned} C_{ij}^L &= \frac{e}{s_W} s_\beta \left(U_{j1}^* N_{i3}^* - \frac{1}{\sqrt{2}} U_{j2}^* (N_{i2}^* + t_W N_{i1}^*)\right), \\ C_{ij}^R &= \frac{e}{s_W} c_\beta \left(V_{j1} N_{i4} + \frac{1}{\sqrt{2}} V_{j2} (N_{i2} + t_W N_{i1})\right), \end{aligned} \tag{2}$$

for convenience, we take $s_W = \sin\theta_W$, $c_W = \cos\theta_W$, $t_W = \tan\theta_W$, $s_\beta = \sin\beta$, $c_\beta = \cos\beta$ and $t_\beta = \tan\beta$.

Here the matrixes U, V and N are the chargino and neutralino mixing matrixes, which can diagonalize the corresponding mass matrixes. The chargino mass matrix is

$$\mathbf{X} = \begin{pmatrix} M & \sqrt{2} m_W s_\beta \\ \sqrt{2} m_W c_\beta & \mu \end{pmatrix} \tag{3}$$

and the neutralino mass matrix is

$$\mathbf{Y} = \begin{pmatrix} M' & 0 & -m_Z s_W c_\beta & m_Z s_W s_\beta \\ 0 & M & m_Z c_W c_\beta & -m_Z c_W s_\beta \\ -m_Z s_W c_\beta & m_Z c_W c_\beta & 0 & -\mu \\ m_Z s_W s_\beta & -m_Z c_W s_\beta & -\mu & 0 \end{pmatrix}. \tag{4}$$

The chargino mixing matrixes (U, V) diagonalize the chargino mass matrix

$$U\mathbf{X}V^\dagger = \text{diag}\left(\eta_1 M_{\widetilde{\chi}_1^-},\, \eta_2 M_{\widetilde{\chi}_2^-}\right), \tag{5}$$

and the neutralino mixing matrix (N) diagonalizes the neutralino mass matrix

$$N\mathbf{Y}N^\dagger = \text{diag}\left(\epsilon_1 M_{\widetilde{\chi}_1^0},\, \epsilon_2 M_{\widetilde{\chi}_2^0},\, \epsilon_3 M_{\widetilde{\chi}_3^0},\, \epsilon_4 M_{\widetilde{\chi}_4^0}\right), \tag{6}$$

where $\eta_i = \pm 1\ (i = 1, 2)$ and $\epsilon_j = \pm 1\ (j = 1, 2, 3, 4)$, these signs depend on the configuration of the mixing matrixes. The chargino and the neutralino physical masses are

$$m_{\widetilde{\chi}_i^-} = \left| M_{\widetilde{\chi}_i^-} \right|,\ m_{\widetilde{\chi}_j^0} = \left| M_{\widetilde{\chi}_j^0} \right|. \tag{7}$$

From the interaction Lagrangian (1) we can derive the tree-level amplitude as following:

$$\mathcal{M}_0 = \overline{u}(p_{\widetilde{\chi}_j^-})(C_{ij}^L P_L + C_{ij}^R P_R) v(p_{\widetilde{\chi}_i^0}). \tag{8}$$

Then the tree-level decay width is thus given by

$$\Gamma_0 = \frac{1}{8\pi} \frac{p_{out}}{m_{H^-}^2} \left| \mathcal{M}_0 \right|^2, \tag{9}$$

where the momentum value of the outgoing particle

$$p_{out} = \frac{1}{2m_{H^-}} \sqrt{(m_{H^-}^2 + m_{\widetilde{\chi}_j^-}^2 - m_{\widetilde{\chi}_i^0}^2)^2 - 4m_{H^-} m_{\widetilde{\chi}_j^-}}. \tag{10}$$

For future convenience, we also present here the vertex $G^+ \widetilde{\chi}_i^- \widetilde{\chi}_j^0$ to fix the renormalization constant of G^- and H^- mixing.

$$\mathcal{L}_{G^+ \widetilde{\chi}_j^- \widetilde{\chi}_i^0} = -G^+ \overline{\widetilde{\chi}_i^0} \left(D_{ij}^L P_L + D_{ij}^R P_R \right) \widetilde{\chi}_j^- + H.c.\,, \tag{11}$$

where $D_{ij}^L = -\cot\beta C_{ij}^L,\ D_{ij}^R = \tan\beta C_{ij}^R$.

3 Virtual Correction

The Feynman diagrams, contributing to the virtual corrections to $H^- \to \widetilde{\chi}_i^0 \widetilde{\chi}_j^-$ are shown in Figs.2-8. In the calculation we use the 't Hooft-Feynman gauge, the dimensional regularization $(D = 4 - 2\epsilon)$ to regularize the ultraviolet (UV) and infrared (IR) divergences in the virtual loop corrections, and the on-mass-shell scheme for the renormalization [11]. We use the FormCalc program [17] to calculate the amplitudes of the one-loop vertex amplitudes and the self-energy diagrams. In order to keep supersymmetry the corrections with the vector bosons are performed by the dimensional reduction.

The relevant renormalization constants for the wave function and the fields mixing have the following definitions:

$$\widetilde{\chi}_{i0}^- = \left(\delta_{ik} + \tfrac{1}{2}\delta Z_{-,ik}^L P_L + \tfrac{1}{2}\delta Z_{-,ik}^R P_R\right)\widetilde{\chi}_k^-,$$

$$\widetilde{\chi}_{i0}^0 = \left(\delta_{ik} + \tfrac{1}{2}\delta Z_{0,ik}^L P_L + \tfrac{1}{2}\delta Z_{0,ik}^R P_R\right)\widetilde{\chi}_k^0,$$

$$\begin{pmatrix} H^- \\ \\ G^- \end{pmatrix}_0 = \begin{pmatrix} 1 + \dfrac{1}{2}\delta Z_{H^-} & \dfrac{1}{2}\delta Z_{H^- G^-} \\ \\ \dfrac{1}{2}\delta Z_{G^- H^-} & 1 + \dfrac{1}{2}\delta Z_{H^-} \end{pmatrix} \begin{pmatrix} H^- \\ \\ G^- \end{pmatrix}. \tag{12}$$

The renormalization constants for the vertex parameters are defined as

$$e_0 = \left(1 + \delta Z_e\right)e, \ s_{W0} = s_W + \delta s_W, \ t_{\beta 0} = t_\beta + \delta t_\beta,$$

$$U_0 = U + \delta U, \ V_0 = V + \delta V, \ N_0 = N + \delta N,$$

$$\delta U = \frac{1}{4}\left(\delta Z_-^L - \delta Z_-^{L\dagger}\right)U, \tag{13}$$

$$\delta V = \frac{1}{4}\left(\delta Z_-^R - \delta Z_-^{R\dagger}\right)V,$$

$$\delta N = \frac{1}{4}\left(\delta Z_0^L - \delta Z_0^{L\dagger}\right)N.$$

With the above rotation matrixes renormalization counterterm definitions, the chargino and neutralino mass matrixes get radiative corrections [18]. The corrections are UV finite shifts on the

tree-level matrixes X and Y. The shift ΔX is

$$
\begin{aligned}
\Delta X_{11} &= 0 && (14)\\
\Delta X_{12} &= \left(\frac{\delta m_W}{m_W} + c_\beta^2\,\frac{\delta t_\beta}{t_\beta}\right)\, X_{12} - \delta X_{12} && (15)\\
\Delta X_{21} &= \left(\frac{\delta m_W}{m_W} - s_\beta^2\,\frac{\delta t_\beta}{t_\beta}\right)\, X_{21} - \delta X_{21} && (16)\\
\Delta X_{22} &= 0\,, && (17)
\end{aligned}
$$

where

$$
(\delta X)_{ij} = \sum_{k=1}^{2}\left[m_{\widetilde{\chi}_k^+}\,(\delta U_{ki}V_{kj} + U_{ki}\delta V_{kj}) + \delta m_{\widetilde{\chi}_k^+} U_{ki}V_{kj}\right]. \qquad (18)
$$

The shift ΔY is

$$
\begin{aligned}
\Delta Y_{11} &= 0 && (19)\\
\Delta Y_{12} &= -\delta Y_{12} && (20)\\
\Delta Y_{13} &= \left(\frac{\delta m_Z}{m_Z} + \frac{\delta s_W}{s_W} - s_\beta^2\,\frac{\delta t_\beta}{t_\beta}\right)\, Y_{13} - \delta Y_{13} && (21)\\
\Delta Y_{14} &= \left(\frac{\delta m_Z}{m_Z} + \frac{\delta s_W}{s_W} + c_\beta^2\,\frac{\delta t_\beta}{t_\beta}\right)\, Y_{14} - \delta Y_{14} && (22)\\
\Delta Y_{22} &= \delta M - \delta Y_{22} && (23)\\
\Delta Y_{23} &= \left(\frac{\delta m_Z}{m_Z} - t_W^2\,\frac{\delta s_W}{s_W} - s_\beta^2\,\frac{\delta t_\beta}{t_\beta}\right)\, Y_{23} - \delta Y_{23} && (24)\\
\Delta Y_{24} &= \left(\frac{\delta m_Z}{m_Z} - t_W^2\,\frac{\delta s_W}{s_W} + c_\beta^2\,\frac{\delta t_\beta}{t_\beta}\right)\, Y_{24} - \delta Y_{24} && (25)\\
\Delta Y_{33} &= -\delta Y_{33} && (26)\\
\Delta Y_{34} &= -\delta\mu - \delta Y_{34} && (27)\\
\Delta Y_{44} &= -\delta Y_{44}\,. && (28)
\end{aligned}
$$

where

$$
(\delta Y)_{ij} = \sum_{k=1}^{4}\left[\delta m_{\widetilde{\chi}_k^0} Z_{ki}Z_{kj} + m_{\widetilde{\chi}_k^0}\delta Z_{ki}Z_{kj} + m_{\widetilde{\chi}_k^0} Z_{ki}\delta Z_{kj}\right]. \qquad (29)
$$

Then the corrected mixing matrixes are $X + \Delta X$ and $Y + \Delta Y$. Through the diagonalization (5) and (6), the corrected pole masses and rotation matrixes can be extracted. Using the corrected couplings, the tree-level decay widths are also changed into the improved tree-level widths [14].

The chargino and the neutralino mixing matrixes renormalization constants cancel the anti-symmetric parts of their wave function renormalization constants. Consequently, the chargino and the neutralino wave function renormalization constants are shifted as,

$$\delta Z_{-} \to \frac{1}{2}(\delta Z_{-} + \delta Z_{-}^{\dagger}),\ \delta Z_{0} \to \frac{1}{2}(\delta Z_{0} + \delta Z_{0}^{\dagger}). \tag{30}$$

Meanwhile, the renormalization for $\tan\beta$ cancels half of the $G^{-} - H^{-}$ renormalization [11] as

$$\delta Z_{G^{-}H^{-}} \to \frac{1}{2}\delta Z_{G^{-}H^{-}}. \tag{31}$$

The renormalized virtual amplitudes can be written as

$$\mathcal{M}_1^V = \mathcal{M}_1^{(v)} + \mathcal{M}_1^{(c)} \tag{32}$$

including the vertex one-loop contribution $\mathcal{M}_1^{(v)}$ and the corresponding counterterm $\mathcal{M}_1^{(c)}$. The vertex part can be derived from the vertex one-loop Feynman diagrams in Fig.2. We list their analytic expressions in Appendix.

With the previous definitions of the renormalization constants, the counterterm Lagrangian for the vertex is

$$\begin{aligned}
\delta\mathcal{L}_{H^{+}\widetilde{\chi}_j^{-}\widetilde{\chi}_i^{0}} = & -H^{+}\overline{\widetilde{\chi}_i^{0}}\Big\{\Big[C_{ij}^{L}\Big(\delta Z_e - \frac{\delta s_W}{s_W} + \frac{1}{2}\delta Z_{H^-} - \frac{1}{4}\cot\beta\delta Z_{G^-H^-}\Big) \\
& + \frac{1}{4}\sum_{k=1}^{2} C_{ik}^{L}\Big(\delta Z_{-,kj}^{L} + \delta Z_{-,jk}^{L*}\Big) + \frac{1}{4}\sum_{k=1}^{4} C_{kj}^{L}\Big(\delta Z_{0,ki}^{L*} + \delta Z_{0,ik}^{L}\Big) - \frac{e s_\beta}{\sqrt{2}s_W}U_{j2}^{*}\delta t_W N_{i1}^{*}\Big]P_L \\
& + \Big[C_{ij}^{R}\Big(\delta Z_e - \frac{\delta s_W}{s_W} + \frac{1}{2}\delta Z_{H^-} + \frac{1}{4}\tan\beta\delta Z_{G^-H^-}\Big) + \frac{1}{4}\sum_{k=1}^{2} C_{ik}^{R}\Big(\delta Z_{-,kj}^{R} + \delta Z_{-,jk}^{R*}\Big) \\
& + \frac{1}{4}\sum_{k=1}^{4} C_{kj}^{L}\Big(\delta Z_{0,ki}^{L*} + \delta Z_{0,ik}^{L}\Big) + \frac{e c_\beta}{\sqrt{2}s_W}V_{i2}\delta t_W N_{j1}\Big]P_R\Big\}\widetilde{\chi}_j^{-}.
\end{aligned} \tag{33}$$

The counterterm amplitude $\mathcal{M}_1^{(c)}$ can be explicitly derived from the above Lagrangian. The renormalization of the input parameters e, θ_W, m_Z and m_W follows the conventional on-mass-shell scheme [11]. The other renormalization constants with the on-mass-shell scheme are defined as follows.

The charged Higgs wave function renormalization constant is

$$\delta Z_{H^-} = -\widetilde{Re}\frac{\partial \Sigma_{H^-H^-}}{\partial p^2}(m_{H^-}^2). \tag{34}$$

The fermion wave function renormalization [11] constants are

$$\delta Z_{ii}^L = -\widetilde{Re}\Big\{\Sigma_{ii}^L(m_i^2) + m_i^2\Big[\frac{\partial \Sigma_{ii}^L}{\partial p^2}(m_i^2) + \frac{\partial \Sigma_{ii}^R}{\partial p^2}(m_i^2)\Big] + m_i\Big[\frac{\partial \Sigma_{ii}^{SL}}{\partial p^2}(m_i^2) + \frac{\partial \Sigma_{ii}^{SR}}{\partial p^2}(m_i^2)\Big]\Big\},$$

$$\delta Z_{ii}^R = -\widetilde{Re}\Big\{\Sigma_{ii}^R(m_i^2) + m_i^2\Big[\frac{\partial \Sigma_{ii}^L}{\partial p^2}(m_i^2) + \frac{\partial \Sigma_{ii}^R}{\partial p^2}(m_i^2)\Big] + m_i\Big[\frac{\partial \Sigma_{ii}^{SL}}{\partial p^2}(m_i^2) + \frac{\partial \Sigma_{ii}^{SR}}{\partial p^2}(m_i^2)\Big]\Big\},$$

$$\delta Z_{ij}^L = \frac{2}{m_i^2 - m_j^2}\widetilde{Re}\Big[m_j^2\Sigma_{ij}^L(m_j^2) + m_i m_j \Sigma_{ij}^R(m_j^2) + m_i\Sigma_{ij}^{SL}(m_j^2) + m_j\Sigma_{ij}^{SR}(m_j^2)\Big], \quad (i \neq j),$$

$$\delta Z_{ij}^R = \frac{2}{m_i^2 - m_j^2}\widetilde{Re}\Big[m_j^2\Sigma_{ij}^R(m_j^2) + m_i m_j \Sigma_{ij}^L(m_j^2) + m_i\Sigma_{ij}^{SR}(m_j^2) + m_j\Sigma_{ij}^{SL}(m_j^2)\Big], \quad (i \neq j). \tag{35}$$

We use the scheme in Ref. [11] to fix $G^- - H^-$ mixing renormalization constant,

$$\delta Z_{G^-H^-} = -\frac{2}{m_W}\widetilde{Re}\Sigma_{H^-W^-}(m_{H^-}^2). \tag{36}$$

Then the renormalization constants could be derived from the self-energy Feynman diagrams shown in Figs.3-8. Through the calculation, the UV divergences of the one-loop vertex and the counterterm are

$$\mathcal{M}_1^{(v)}\Big|_{UV} = \Big(-\frac{1}{\epsilon}\Big)\Big\{\Big[\frac{\alpha}{16\pi m_W^2 s_\beta^2 s_W^2}[s_\beta^2(m_Z^2 + 18m_W^2) + \sum_{g=1}^{3} 6m_{u_g}^2] + \frac{\alpha e c_\beta}{\sqrt{2}\pi s_W^2 c_W}N_{i1}V_{j2}\Big]C_{ij}^R P_R$$

$$+\Big[\frac{\alpha}{16\pi m_W^2 c_\beta^2 s_W^2}[c_\beta^2(m_Z^2 + 18m_W^2) + \sum_{g=1}^{3}(6m_{d_g}^2 + 2m_{e_g}^2)] - \frac{\alpha e s_\beta}{\sqrt{2}\pi s_W^2 c_W}N_{i1}U_{j2}\Big]C_{ij}^L P_L\Big\}, \tag{37}$$

$$\mathcal{M}_1^{(c)}\Big|_{UV} = \frac{1}{\epsilon}\Big\{\Big[\frac{\alpha}{16\pi m_W^2 s_\beta^2 s_W^2}[s_\beta^2(m_Z^2 + 18m_W^2) + \sum_{g=1}^{3} 6m_{u_g}^2] + \frac{\alpha e c_\beta}{\sqrt{2}\pi s_W^2 c_W}N_{i1}V_{j2}\Big]C_{ij}^R P_R$$

$$+\Big[\frac{\alpha}{16\pi m_W^2 c_\beta^2 s_W^2}[c_\beta^2(m_Z^2 + 18m_W^2) + \sum_{g=1}^{3}(6m_{d_g}^2 + 2m_{l_g}^2)] - \frac{\alpha e s_\beta}{\sqrt{2}\pi s_W^2 c_W}N_{i1}U_{j2}\Big]C_{ij}^L P_L\Big\}, \tag{38}$$

where, m_{u_g}, m_{d_g} and m_{l_g} represent the mass of the u-type quarks, the d-type quarks and the leptons, and g is the generation index.

Obviously, the UV divergences of $\mathcal{M}_1^{(v)}$ and $\mathcal{M}_1^{(c)}$ can cancel each other, as they must. Then the renormalized amplitude at one-loop order is UV convergent

$$\mathcal{M}_1^V\Big|_{UV} = 0. \tag{39}$$

Thus the full one-loop virtual correction for the decay width is

$$\Gamma_V = \frac{1}{8\pi}\frac{p_{out}}{m_{H^-}^2} 2Re(\mathcal{M}_0\mathcal{M}_1^{V*}), \tag{40}$$

where the renormalized amplitude $\mathcal{M}_1^V$ is UV finite, but it still contains infrared (IR) divergences, which can be written as:

$$\mathcal{M}_1^V\Big|_{IR} = \frac{\alpha}{2\pi}\frac{1}{\epsilon}\Big[-2 + \frac{2x_1x_2 - x_1 - x_2}{x_1 - x_2}\ln\Big(\frac{x_1x_2 - x_2}{x_1x_2 - x_1}\Big)\Big]\mathcal{M}_0, \tag{41}$$

where,

$$x_{1,2} = \frac{m_{H^-}^2 - m_{\tilde{\chi}_j^-}^2 + m_{\tilde{\chi}_i^0}^2 \pm 2m_{H^-}p_{out}}{2m_{\tilde{\chi}_i^0}^2}. \tag{42}$$

The IR divergences can be cancelled after adding the contributions from the emission of real photons, which will be described in detail in the following section.

4 Real Correction

The Feynman diagrams for the real corrections are shown in Fig.1.

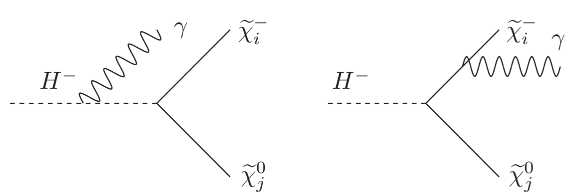

Figure 1: The photon emission Feynman diagrams.

The relevant three-body decay width is

$$\Gamma_R = \frac{1}{2\Phi}\int\overline{\sum}|\mathcal{M}_3|^2 dPS^{(3)}, \tag{43}$$

where $\Phi = m_{H^-}$ is the usual flux factor for the one particle initial state. $dPS^{(3)}$ is the three-body phase space. $\overline{\sum}|\mathcal{M}_3|^2$ is the squared amplitude averaged over the initial degrees of freedom,

$$\overline{\sum}|\mathcal{M}_3|^2 = \frac{2e^2}{(p_{\widetilde{\chi}^-}\cdot\ p_\gamma)^2}[-m^2_{\widetilde{\chi}^-}(p_{\widetilde{\chi}^0}\cdot\ p_\gamma) - m^2_{\widetilde{\chi}^-}(p_{\widetilde{\chi}^-}\cdot\ p_{\widetilde{\chi}^0}) + (p_{\widetilde{\chi}^-}\cdot\ p_\gamma)(p_{\widetilde{\chi}^0}\cdot\ p_\gamma)](C_L C_R^\dagger + C_R C_L^\dagger)$$

$$+\frac{2e^2}{(p_{\widetilde{\chi}^-}\cdot\ p_\gamma)^2} m_{\widetilde{\chi}^-} m_{\widetilde{\chi}^0}[m^2_{\widetilde{\chi}^-} + (p_{\widetilde{\chi}^-}\cdot\ p_\gamma)](C_L C_L^\dagger + C_R C_R^\dagger) + \frac{2e^2}{[(p_{\widetilde{\chi}^-}\cdot\ p_\gamma) + (p_{\widetilde{\chi}^0}\cdot\ p_\gamma)]^2}$$

$$\times[m^2_{\widetilde{\chi}^-} + m^2_{\widetilde{\chi}^0} + 2(p_{\widetilde{\chi}^-}\cdot\ p_{\widetilde{\chi}^0}) + (p_{\widetilde{\chi}^-}\cdot\ p_\gamma) + (p_{\widetilde{\chi}^0}\cdot\ p_\gamma)][-(p_{\widetilde{\chi}^-}\cdot\ p_{\widetilde{\chi}^0})(C_L C_R^\dagger + C_R C_L^\dagger)$$

$$+m_{\widetilde{\chi}^-} m_{\widetilde{\chi}^0}(C_L C_L^\dagger + C_R C_R^\dagger)] + \frac{2e^2}{(p_{\widetilde{\chi}^-}\cdot\ p_\gamma)[(p_{\widetilde{\chi}^-}\cdot\ p_\gamma) + (p_{\widetilde{\chi}^0}\cdot\ p_\gamma)]}[2m^2_{\widetilde{\chi}^-}(p_{\widetilde{\chi}^-}\cdot\ p_{\widetilde{\chi}^0})$$

$$+2(p_{\widetilde{\chi}^-}\cdot\ p_{\widetilde{\chi}^0})^2 + 2(p_{\widetilde{\chi}^-}\cdot\ p_{\widetilde{\chi}^0})(p_{\widetilde{\chi}^0}\cdot\ p_\gamma) + (p_{\widetilde{\chi}^-}\cdot\ p_{\widetilde{\chi}^0})(p_{\widetilde{\chi}^0}\cdot\ p_\gamma) + m^2_{\widetilde{\chi}^-}(p_{\widetilde{\chi}^0}\cdot\ p_\gamma)$$

$$-4m^2_{\widetilde{\chi}^0}(p_{\widetilde{\chi}^-}\cdot\ p_\gamma)](C_L C_R^\dagger + C_R C_L^\dagger) + \frac{2e^2}{(p_{\widetilde{\chi}^-}\cdot\ p_\gamma)[(p_{\widetilde{\chi}^-}\cdot\ p_\gamma) + (p_{\widetilde{\chi}^0}\cdot\ p_\gamma)]}(-m_{\widetilde{\chi}^-} m_{\widetilde{\chi}^0})$$

$$\times[2m^2_{\widetilde{\chi}^-} + 2(p_{\widetilde{\chi}^-}\cdot\ p_\gamma) + (p_{\widetilde{\chi}^0}\cdot\ p_\gamma) + 2(p_{\widetilde{\chi}^-}\cdot\ p_{\widetilde{\chi}^0})](C_L C_L^\dagger + C_R C_R^\dagger)$$

where $p_{\widetilde{\chi}^-}$, $p_{\widetilde{\chi}^0}$ and p_γ is the relevant four dimensional momentums.

The IR singularities arise from the phase space integration for the real soft photon emission, which can be conveniently isolated by slicing the space into two regions defined by suitable cut-off δ_s, according to whether the energy of the emitted photon is soft, i.e. $E_\gamma \le \delta_s m_{H^-}/2$, or not. Correspondingly, the three-body decay width can be written into two parts as following.

$$\frac{1}{2\Phi}\int \overline{\sum}|\mathcal{M}_3|^2 dPS^{(3)} = \frac{1}{2\Phi}\int_{soft} \overline{\sum}|\mathcal{M}_3|^2 dPS^{(3)} + \frac{1}{2\Phi}\int_{hard} \overline{\sum}|\mathcal{M}_3|^2 dPS^{(3)}, \quad (44)$$

where the corresponding parts are Γ_{soft} and Γ_{hard} respectively.

The hard part Γ_{hard} is IR finite and can be numerically calculated using the Cuba program [20]. The IR divergences only live in the soft part Γ_{soft}. Using the eikonal approximation, the soft part can be factorized into an IR factor, multiplied by the tree-level decay width.

$$\Gamma_{soft} = \delta_{IR}\Gamma_0, \quad (45)$$

where

$$\delta_{IR} = \frac{\alpha}{2\pi}\Big\{\frac{1}{\epsilon}\Big[2 - \frac{2x_1x_2 - x_1 - x_2}{x_1 - x_2}\ln\Big(\frac{x_1x_2 - x_2}{x_1x_2 - x_1}\Big)\Big] + \Big[\ln\Big(\frac{4\pi\mu^2}{\delta_s^2 m_{H^-}^2}\Big) - \gamma_E\Big]$$

$$\times\Big[2 - \frac{2x_1x_2 - x_1 - x_2}{x_1 - x_2}\ln\Big(\frac{x_1x_2 - x_2}{x_1x_2 - x_1}\Big)\Big] + 2 + \frac{2x_1x_2 - x_1 - x_2}{x_1 - x_2} \tag{46}$$

$$\times\Big[\ln\Big(\frac{x_1x_2 - x_2}{x_1x_2 - x_1}\Big) - 2Li_2\Big(\frac{2(x_1 - x_2)}{x_1x_2 - x_2}\Big) - \frac{1}{2}\ln^2\Big(\frac{x_1x_2 - x_2}{x_1x_2 - x_1}\Big)\Big]\Big\}.$$

From Eq.(41) and Eq.(46) we can see that the IR divergences in Γ_V and Γ_R can be cancelled. Finally, summing up the tree-level, the virtual and the real corrections, the decay width of $H^- \to \widetilde{\chi}^-\widetilde{\chi}^0$, including the FEW corrections, is

$$\Gamma = \Gamma_0 + \Gamma_V + \Gamma_R. \tag{47}$$

5 Numerical Results

We now present some numerical results of two charged Higgs decay modes: $H^- \to \widetilde{\chi}_1^-\widetilde{\chi}_1^0$ (mode 1) and $H^- \to \widetilde{\chi}_1^-\widetilde{\chi}_2^0$ (mode 2), which are dominant decay modes allowed by kinetics. The SM input parameters are chosen as follows [21],

$$\begin{array}{lll} m_Z = 91.1875GeV, & m_W = 80.45GeV, & \alpha_{EW} = 1/137, \\ m_e = 0.51MeV, & m_\mu = 105.658MeV, & m_\tau = 1.777GeV, \\ m_u = 53.8MeV, & m_c = 1.5GeV, & m_t = 178GeV, \\ m_d = 53.8MeV, & m_s = 150MeV, & m_b = 4.7GeV. \end{array}$$

As mentioned in Ref. [19], the masses of the up and down quarks are effective parameters which are adjusted such that the five-flavor hadronic contribution to $\Delta\alpha$ is 0.02788 [22], ie

$$\Delta\alpha_{\text{had}}^{(5)}(s = M_Z^2) = \frac{\alpha}{\pi}\sum_{f=u,c,d,s,b} q_f^2\Big(\log\frac{M_Z^2}{m_f^2} - \frac{5}{3}\Big) \stackrel{!}{=} 0.02778\,.$$

For the phenomenological MSSM parameters, we choose all the parameters are real and use the suspect program [19] to calculate the particle spectrum. Our calculations are mainly based on the relevant inputs as following unless specified:

$$m_{H^-} = 250GeV, \qquad m_{\widetilde{\chi}_1^-} = 100GeV, \qquad m_{\widetilde{\chi}_2^-} = 300GeV, \qquad m_{\widetilde{\chi}_1^0} = 60GeV,$$

$$m_{\widetilde{Q}} = m_{\widetilde{U}} = m_{\widetilde{D}} = m_{\widetilde{E}} = m_{\widetilde{L}} = A_t = A_b = A_\tau = M_{SUSY} = 200 GeV.$$

With the above chargino and neutralino masses, the fundamental parameters M, M' and μ are extracted from the tree-level mass matrixes (3) and (4), assuming $\mu < 0$ and the magnitude of M is always larger than that of μ. The above input parameters are consistent with all the existing experiment data [21]. With the these mass parameters, we calculate out the basic phenomenological MSSM parameters. Note that the inputs are the same as the ones in Ref. [11]. But we vary $\tan\beta$, m_{H^-}, $m_{\widetilde{\chi}_1^-}$ and $m_{\widetilde{\chi}_1^0}$ to examine their effects on the decay widths.

Fig.9 presents the dependence of the FEW corrected decay width on the arbitrary soft cut-off scale δ_s, introduced in the PSS method. As δ_s varies from 10^{-1} to 10^{-9}, the uncertainty of the decay width is below $\pm 0.1\%$. Therefore we set the soft cut-off scale δ_s as 10^{-5} through our numerical calculations.

When we include the corrections as shown in Eqs.(14)-(29) from mixing matrixes , the sequence of the masses of the neutralino 2 and 3 will be exchanged. Consequently, the second and the third row in the rotation matrix N will be exchanged. This is so-called level crossings [23]. To prove this viewpoint, we force to exchange back between neutralino 2 and 3. Fig.10 shows the LO corrections before and after the exchanging. We can see the corrections after exchanging are almost the same as the corresponding corrections in Ref. [11].

Fig.11 shows that the improved tree-level decay width and the LO, the CLO and the FEW corrected decay width as the functions of $\tan\beta$, respectively. As $\tan\beta \geq 4$, the LO corrections increases the tree-level decay width for the decay mode 1 and slightly decreases it for the decay mode 2.

Fig.12 shows the LO, the CLO and the FEW relative corrections as the functions of $\tan\beta$, respectively. As $\tan\beta$ ranges between 2 and 50, all the corrections keep increasing with the increasing of $\tan\beta$ for the decay mode 1, which can reach 30%, and vary between 5% and -15% for the decay mode 2. Comparing with the LO corrections, the FEW and the CLO corrections for the mode 1 are in general larger by almost 6% and 3%, respectively. From Fig.12, we can also see the changes of FEW and CLO corrections for the mode 2 are not negligible, and the LO corrections are no longer important as $\tan\beta < 5$ for the mode 1 and $\tan\beta > 45$ for the mode 2, since in these conditions the quark mass-dependent terms in the $\widetilde{\chi}\widetilde{q}\bar{q}$ vertexes are small and the

mass-independent terms are important, thus the contributions from the first and second generation quarks should also be significant. Moreover, we find that the curves for the LO corrections of the mode 1 are almost the same as that in Ref. [11]. However, the curve for LO corrections of the mode 2 is different due to the level crossings as discussed above. For the same reason, the FEW corrections for the mode 1 and 2 are changed to each other for $\tan\beta = 33.1$.

Fig.13 shows the LO, the CLO and the FEW corrections for $\tan\beta = 4$ as the functions of m_{H^-}, respectively. These corrections are not very sensitive to m_{H^-} for the decay mode 1, and have a little dependence of m_{H^-} for the decay mode 2. As m_{H^-} ranges between 250GeV and 600GeV, the corrections do not change too much. Comparing with the LO and the CLO corrections, in general, the FEW corrections for the mode 1 increase about 6% and 2%, respectively, and the magnitude of the FEW corrections for the mode 2 can increase about 8% and 6%, respectively. There are many dips on the curves, which come from the singularities at the threshold points, for example, respective ones of which on the LO and the CLO corrections curves are shown as following:

$$
\begin{aligned}
m_{H^-}(396.2GeV) &= m_{\tilde{t}_1}(186.6GeV) + m_{\tilde{b}_1}(209.6GeV),\\
m_{H^-}(407.0GeV) &= m_{\tilde{t}_1}(186.6GeV) + m_{\tilde{b}_2}(220.4GeV),\\
m_{H^-}(535.4GeV) &= m_{\tilde{t}_2}(325.8GeV) + m_{\tilde{b}_1}(209.6GeV).
\end{aligned}
$$

Moreover, there are also more little dips appearing on the curves of the FEW corrections that come from the singularities of other loop Feynman diagrams.

Fig.14 gives almost the same case as Fig.13 except $\tan\beta = 30$. Comparing with the LO and the CLO corrections, in general, the FEW corrections for the mode 1 increase about 5% and 2%, respectively, and the magnitude of the FEW corrections for the mode 2 can increase about 14% and 10%, respectively. The respective dips on the LO and the CLO corrections curves, arising from the singularities at the threshold points, are

$$
\begin{aligned}
m_{H^-}(377.6GeV) &= m_{\tilde{t}_1}(195.8GeV) + m_{\tilde{b}_1}(181.8GeV),\\
m_{H^-}(439.9GeV) &= m_{\tilde{t}_1}(195.8GeV) + m_{\tilde{b}_2}(244.1GeV),\\
m_{H^-}(501.0GeV) &= m_{\tilde{t}_2}(319.2GeV) + m_{\tilde{b}_1}(181.8GeV),\\
m_{H^-}(563.3GeV) &= m_{\tilde{t}_2}(319.2GeV) + m_{\tilde{b}_2}(244.1GeV).
\end{aligned}
$$

Moreover, there are also more little dips on the curves of the FEW corrections. In comparison, the results of the LO corrections shown in Figs.13 and 14 agree with the ones in Ref. [11].

Fig.15 gives the LO, the CLO and the FEW corrections to $H^- \to \widetilde{\chi}_1^- \widetilde{\chi}_1^0$ as the functions of $m_{\widetilde{\chi}_1^-}$ for $\tan\beta = 4$ and 30, respectively. The LO corrections are about 1% for $\tan\beta = 4$ and generally vary from 4% to 8% for $\tan\beta = 30$. Comparing with the LO corrections, in general, for both above cases the CLO corrections increase about 3%, and the FEW corrections increase about 5%, respectively.

Fig.16 presents the LO, the CLO and the FEW corrections to $H^- \to \widetilde{\chi}_1^- \widetilde{\chi}_1^0$ as the functions of $m_{\widetilde{\chi}_1^0}$, respectively. Here, we choose the same parameters as above except $m_{\widetilde{\chi}_1^-} = 128$GeV. When $\tan\beta = 4$, the LO and the CLO corrections almost do not change, and the FEW corrections slightly decrease with the increasing of $m_{\widetilde{\chi}_1^0}$. When $\tan\beta = 30$, all three corrections increase with the increasing of $m_{\widetilde{\chi}_1^0}$. Comparing with the LO corrections, in general, the CLO corrections increase about 3%, and the FEW corrections increase about 5%, respectively.

In the following calculations, the MSSM parameters are constrained within the mSUGRA [16], in which there are only five free input parameters, i.e. $m_{1/2}, m_0, A_0, \tan\beta$ and sign of μ, where $m_{1/2}, m_0, A_0$ are the universal gaugino mass, scalar mass at GUT scale and the trilinear soft breaking parameter in the superpotential terms, respectively.

Fig.17 shows the LO, the CLO and the FEW corrections as the functions of m_0 ranging between 0 and 1000GeV, respectively, assuming $m_{1/2} = 200$GeV, $A_0 = 0$ and $\tan\beta = 10$. We find that for both decay modes the LO and the CLO corrections only slightly change as m_0 varies. For the decay mode 1, the FEW corrections can be larger than the LO and the CLO corrections by 18% and 14%, respectively. For the decay mode 2, the FEW corrections can be larger than the LO corrections by 50%, and than the CLO corrections by 60%.

Fig.18 gives the LO, the CLO and the FEW corrections as the functions of A_0, respectively, assuming $m_{1/2} = 200$GeV, $m_0 = 200$GeV and $\tan\beta = 10$. The LO and the CLO corrections almost do not change with varying of A_0, but the FEW corrections change much. The FEW corrections can be larger than the LO and the CLO corrections by about 18% and 13% for the decay mode 1, respectively. For the decay mode 2, the FEW corrections tend to decrease and can be larger than the LO and the CLO corrections by about 30% and 25%, respectively.

In conclusion, we have calculated the FEW corrections to the charged Higgs decays into

a neutralino and chargino in the MSSM, and compared with the LO and the CLO corrections. Our results show that the magnitudes of the FEW corrections can be larger than 10% for both decay modes for $\tan\beta > 30$. Moreover, comparing with the FEW corrections, both of the LO and the CLO corrections are negligible small for the mode 1 when $\tan\beta < 5$, and for the mode 2 when $\tan\beta > 45$, respectively, since there are not enhancements from the Yukawa couplings. We have also calculated the FEW corrections in the mSUGRA scenario, where the FEW corrections can be larger than the LO and the CLO corrections by more than 60% and 50%, respectively. Thus the FEW corrections are significant, which might be observable in the future high precision experiments for Higgs physics.

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Appendix

In this appendix, we list the explicit expressions for the vertex one-loop amplitude. The vertex one-loop amplitudes are expanded with two Dirac matrix elements [24] with 35 coefficients for each of them, corresponding to the 35 Feynman diagrams in Fig.2.

$$\mathcal{M}_1^{(v)} = \sum_{i=1}^{35} (f_1^i F_1 + f_2^i F_2), \tag{48}$$

where,

$$F_1 = \overline{u}(p_{\tilde{\chi}_j^-}) P_R v(p_{\tilde{\chi}_i^0}), \quad F_2 = \overline{u}(p_{\tilde{\chi}_j^-}) P_L v(p_{\tilde{\chi}_i^0}). \tag{49}$$

In our paper, we use the Passarino-Veltman integrals, which are defined in Ref. [24]. For simplicity, we define the notations as following:

$$c^1_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\tilde{\chi}_j^-}, \mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\tilde{\chi}_{c_1}^-}, \mathbf{m}^2_{h^0}, \mathbf{m}^2_{\tilde{\chi}_{n_1}^0}), \quad b^1_0 = \mathbf{B_0}(\mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{h^0}, \mathbf{m}^2_{\tilde{\chi}_{n_1}^0})$$

$$c^2_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\tilde{\chi}_j^-}, \mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\tilde{\chi}_{c_1}^-}, \mathbf{m}^2_{H^0}, \mathbf{m}^2_{\tilde{\chi}_{n_1}^0}), \quad b^2_0 = \mathbf{B_0}(\mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{H^0}, \mathbf{m}^2_{\tilde{\chi}_{n_1}^0})$$

$$c^3_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\tilde{\chi}_j^-}, \mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\tilde{\chi}_{c_1}^-}, \mathbf{m}^2_{A^0}, \mathbf{m}^2_{\tilde{\chi}_{n_1}^0}), \quad b^3_0 = \mathbf{B_0}(\mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{A^0}, \mathbf{m}^2_{\tilde{\chi}_{n_1}^0})$$

$$c^4_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\tilde{\chi}_j^-}, \mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\tilde{\chi}_{c_1}^-}, \mathbf{m}^2_{Z}, \mathbf{m}^2_{\tilde{\chi}_{n_1}^0}), \quad b^4_0 = \mathbf{B_0}(\mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{Z}, \mathbf{m}^2_{\tilde{\chi}_{n_1}^0})$$

$$c^5_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\tilde{\chi}_j^-}, \mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\tilde{\chi}_{n_1}^-}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\tilde{\chi}_{c_1}^0}), \quad b^5_0 = \mathbf{B_0}(\mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\tilde{\chi}_{c_1}^0})$$

$$c^6_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\tilde{\chi}_j^-}, \mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\tilde{\chi}_{n_1}^-}, \mathbf{m}^2_{W}, \mathbf{m}^2_{\tilde{\chi}_{c_1}^0}), \quad b^6_0 = \mathbf{B_0}(\mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{W}, \mathbf{m}^2_{\tilde{\chi}_{c_1}^0})$$

$$c^7_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\tilde{\chi}_j^-}, \mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{e_{g_1}}, \mathbf{m}^2_{\tilde{\nu}_{g_1}}, 0), \quad b^7_0 = \mathbf{B_0}(\mathbf{m}^2_{\tilde{\chi}_i^0}, 0, \mathbf{m}^2_{\tilde{\nu}_{g_1}})$$

$$c^8_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{H^-}, \mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{\tilde{\chi}_j^-}, 0, \mathbf{m}^2_{e_{g_1}}, \mathbf{m}^2_{\tilde{e}_{s_1 g_1}}), \quad b^8_0 = \mathbf{B_0}(\mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{e_{g_1}}, \mathbf{m}^2_{\tilde{e}_{s_1 g_1}})$$

$$c^9_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{H^-}, \mathbf{m}^2_{\tilde{\chi}_j^-}, \mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{u_{g_2}}, \mathbf{m}^2_{d_{g_1}}, \mathbf{m}^2_{\tilde{u}_{s_1 g_1}}), \quad b^9_0 = \mathbf{B_0}(\mathbf{m}^2_{\tilde{\chi}_j^-}, \mathbf{m}^2_{d_{g_1}}, \mathbf{m}^2_{\tilde{u}_{s_1 g_2}})$$

$$c^{10}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{H^-}, \mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{\tilde{\chi}_j^-}, \mathbf{m}^2_{u_{g_1}}, \mathbf{m}^2_{d_{g_2}}, \mathbf{m}^2_{\tilde{d}_{s_1 g_2}}), \quad b^{10}_0 = \mathbf{B_0}(\mathbf{m}^2_{\tilde{\chi}_i^0}, \mathbf{m}^2_{d_{g_2}}, \mathbf{m}^2_{\tilde{u}_{s_1 g_2}})$$

$$c^{11}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\widetilde{\chi}^0_{n_1}}, \mathbf{m}^2_{h^0})$$

$$c^{12}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{h^0}, \mathbf{m}^2_{\widetilde{\chi}^-_{c_1}}, \mathbf{m}^2_{H^-})$$

$$c^{13}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\widetilde{\chi}^0_{n_1}}, \mathbf{m}^2_{H^0})$$

$$c^{14}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{H^0}, \mathbf{m}^2_{\widetilde{\chi}^-_{c_1}}, \mathbf{m}^2_{H^-})$$

$$c^{15}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{W}, \mathbf{m}^2_{\widetilde{\chi}^0_{n_1}}, \mathbf{m}^2_{h^0})$$

$$c^{16}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{h^0}, \mathbf{m}^2_{\widetilde{\chi}^-_{c_1}}, \mathbf{m}^2_{W})$$

$$c^{17}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{W}, \mathbf{m}^2_{\widetilde{\chi}^0_{n_1}}, \mathbf{m}^2_{H^0})$$

$$c^{18}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{H^0}, \mathbf{m}^2_{\widetilde{\chi}^-_{c_1}}, \mathbf{m}^2_{W})$$

$$c^{19}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{W}, \mathbf{m}^2_{\widetilde{\chi}^0_{n_1}}, \mathbf{m}^2_{A^0})$$

$$c^{20}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{A^0}, \mathbf{m}^2_{\widetilde{\chi}^-_{c_1}}, \mathbf{m}^2_{W})$$

$$c^{21}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\widetilde{e}_{s_1 g_1}}, 0, \mathbf{m}^2_{\widetilde{\nu}_{g_1}})$$

$$c^{22}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{e_{g_1}}, \mathbf{m}^2_{\widetilde{\nu}_{g_1}}, \mathbf{m}^2_{\widetilde{e}_{s_1 g_1}})$$

$$c^{23}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{u_{g_2}}, \mathbf{m}^2_{\widetilde{d}_{s_1 g_1}} \mathbf{m}^2_{\widetilde{u}_{s_2 g_2}})$$

$$c^{24}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{d_{g_2}}, \mathbf{m}^2_{\widetilde{u}_{s_1 g_1}}, \mathbf{m}^2_{\widetilde{d}_{s_2 g_2}})$$

$$c^{25}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\widetilde{\chi}^-_{c_1}}, \mathbf{m}^2_{Z}, \mathbf{m}^2_{\widetilde{\chi}^0_{n_1}}), \quad b^{25}_0 = \mathbf{B_0}(\mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{Z}, \mathbf{m}^2_{\widetilde{\chi}^0_{n_1}})$$

$$c^{26}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\widetilde{\chi}^-_{n_1}}, \mathbf{m}^2_{W}, \mathbf{m}^2_{\widetilde{\chi}^0_{c_1}}), \;\; b^{26}_0 = \mathbf{B_0}(\mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_W, \mathbf{m}^2_{\widetilde{\chi}^-_{c_1}})$$

$$c^{27}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\widetilde{\chi}^0_{n_1}}, \mathbf{m}^2_{Z}), \;\; b^{27}_0 = \mathbf{B_0}(\mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_Z, \mathbf{m}^2_{\widetilde{\chi}^-_{n_1}})$$

$$c^{28}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{h^0}, \mathbf{m}^2_{\widetilde{\chi}^-_{c_1}}, \mathbf{m}^2_{W}), \;\; b^{28}_0 = \mathbf{B_0}(\mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_W, \mathbf{m}^2_{\widetilde{\chi}^-_{c_1}})$$

$$c^{29}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{H^0}, \mathbf{m}^2_{\widetilde{\chi}^-_{c_1}}, \mathbf{m}^2_{W}), \;\; b^{29}_0 = \mathbf{B_0}(\mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_W, \mathbf{m}^2_{\widetilde{\chi}^-_{c_1}})$$

$$c^{30}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{A^0}, \mathbf{m}^2_{\widetilde{\chi}^-_{c_1}}, \mathbf{m}^2_{W}), \;\; b^{30}_0 = \mathbf{B_0}(\mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_W, \mathbf{m}^2_{\widetilde{\chi}^-_{c_1}})$$

$$c^{31}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, 0, \mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{H^-}), \;\; b^{31}_0 = \mathbf{B_0}(\mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\widetilde{\chi}^-_j})$$

$$c^{32}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{Z}, \mathbf{m}^2_{\widetilde{\chi}^-_{c_1}}, \mathbf{m}^2_{H^-}), \;\; b^{32}_0 = \mathbf{B_0}(\mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{\widetilde{\chi}^-_{c_1}})$$

$$c^{33}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{W}, \mathbf{m}^2_{\widetilde{\chi}^0_{n_1}}, \mathbf{m}^2_{h^0}), \;\; b^{33}_0 = \mathbf{B_0}(\mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{h^0}, \mathbf{m}^2_{\widetilde{\chi}^0_{n_1}})$$

$$c^{34}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{W}, \mathbf{m}^2_{\widetilde{\chi}^0_{n_1}}, \mathbf{m}^2_{H^0}), \;\; b^{34}_0 = \mathbf{B_0}(\mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^0}, \mathbf{m}^2_{\widetilde{\chi}^0_{n_1}})$$

$$c^{35}_{(0,1,2)} = \mathbf{C_{(0,1,2)}}(\mathbf{m}^2_{\widetilde{\chi}^-_j}, \mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{H^-}, \mathbf{m}^2_{W}, \mathbf{m}^2_{\widetilde{\chi}^0_{n_1}}, \mathbf{m}^2_{A^0}), \;\; b^{35}_0 = \mathbf{B_0}(\mathbf{m}^2_{\widetilde{\chi}^0_i}, \mathbf{m}^2_{A^0}, \mathbf{m}^2_{\widetilde{\chi}^0_{n_1}})$$

We also define some abbreviations for the frequent combinations as following:

$$\mathcal{X}^1_{ab} = (c_W N_{a2} - s_W N_{a1})(s_\alpha N_{b3} + c_\alpha N_{b4}) + (c_W N_{b2} - s_W N_{b1})(s_\alpha N_{a3} + c_\alpha N_{a4})$$

$$\mathcal{X}^2_{ab} = (c_W N_{a2} - s_W N_{a1})(c_\alpha N_{b3} - s_\alpha N_{b4}) + (c_W N_{b2} - s_W N_{b1})(c_\alpha N_{a3} - s_\alpha N_{a4})$$

$$\mathcal{X}^3_{ab} = (c_W N_{a2} - s_W N_{a1})(c_\beta N_{b4} - s_\beta N_{b3}) + (c_W N_{b2} - s_W N_{b1})(c_\beta N_{a4} - s_\beta N_{a3})$$

$$\mathcal{X}^4_{ab} = (c_W N_{a2} - s_W N_{a1})(c_\beta N_{b3} + s_\beta N_{b4}) + (c_W N_{b2} - s_W N_{b1})(c_\beta N_{a3} + s_\beta N_{a4})$$

$$\mathcal{X}^8_{gs} = c_\beta \mathbf{m}_W R^{\widetilde{e}_g *}_{s1}(s_W N_{i1} + c_W N_{i2}) - c_W \mathbf{m}_{e_g} R^{\widetilde{e}_g *}_{s2} N_{i3}$$

$$\mathcal{X}^9_{gs} = 2\mathbf{m}_W s_\beta R^{\widetilde{u}_g *}_{s1} V_{j1} - \sqrt{2}\mathbf{m}_{u_g} R^{\widetilde{u}_g *}_{s2} V_{j2}$$

$$\mathcal{X}^{10}_{gs} = 2c_\beta \mathbf{m}_W U^*_{j1} R^{\widetilde{d}_g}_{s1} - \sqrt{2}\mathbf{m}_{d_g} U^*_{j2} R^{\widetilde{d}_g}_{s2}$$

$$\mathcal{X}^{21}_{gs} = (\mathbf{m}^2_W s_{2\beta} - t_\beta \mathbf{m}^2_{e_g}) R^{\widetilde{e}_g *}_{s1} - (\mu + t_\beta \mathbf{A}^*_{e_g})\mathbf{m}_{e_g} R^{\widetilde{e}_g *}_{s2}$$

$$\mathcal{X}^{25}_{jc} = s^2_W \delta_{c,j} - \mathbf{U}_{c1}\mathbf{U}^*_{j1} - \frac{1}{2}\mathbf{U}_{c2}\mathbf{U}^*_{j2}$$

$$\mathcal{X}^{26}_{cn} = U^*_{c1} N_{n2} + U^*_{c2} N_{n3}/\sqrt{2}$$

$$\mathcal{Y}^1_{ab} = s_\alpha U_{a2} V_{b1} - c_\alpha U_{a1} V_{b2}, \qquad \mathcal{Y}^2_{ab} = c_\alpha U_{a2} V_{b1} + s_\alpha U_{b1} V_{a2}$$

$$\mathcal{Y}^3_{ab} = s_\beta U_{a2} V_{b1} + c_\beta U_{a1} V_{b2}, \qquad \mathcal{Y}^4_{ab} = s_\beta U_{a1} V_{b2} - c_\beta U_{a2} V_{b1}$$

$$\mathcal{Y}^8_{gs} = -2U^*_{j1} R^{\widetilde{e}_g}_{s1} + \sqrt{2}\mathbf{m}_{e_g} U^*_{j2} R^{\widetilde{e}_g}_{s2}/(c_\beta \mathbf{m}_W)$$

$$\mathcal{Y}^9_{gs} = 4\mathbf{m}_W s_\beta s_W R^{\widetilde{u}_g}_{s2} N_{i1} - 3c_W \mathbf{m}_{u_g} R^{\widetilde{u}_g}_{s1} N_{i4}$$

$$\mathcal{Y}^{10}_{gs} = (2c_\beta \mathbf{m}_W s_W R^{\widetilde{d}_g *}_{s2} N^*_{i1} + 3c_W \mathbf{m}_{d_g} R^{\widetilde{d}_g *}_{s1} N^*_{i3})\mathbf{m}_{d_g}$$

$$\mathcal{Y}^{25}_{cj} = s^2_W \delta_{c,j} - \mathbf{V}_{j1}\mathbf{V}^*_{c1} - \frac{1}{2}\mathbf{V}_{j2}\mathbf{V}^*_{c2}$$

$$\mathcal{Y}^{26}_{cn} = V^*_{c1} N_{n2} - V^*_{c2} N_{n4}/\sqrt{2}$$

$$\mathcal{Z}^8_{gs} = 2c_\beta \mathbf{m}_W s_W R^{\widetilde{e}_g *}_{s2} N^*_{i1} + c_W \mathbf{m}_{e_g} R^{\widetilde{e}_g *}_{s1} N^*_{i3}$$

$$\mathcal{Z}^9_{gs} = \mathbf{m}_W s_\beta R^{\widetilde{u}_g}_{s1}(s_W N^*_{i1} + 3c_W N^*_{i2}) + 3c_W \mathbf{m}_{u_g} R^{\widetilde{u}_g}_{s2} N^*_{i4}$$

$$\mathcal{Z}^{10}_{gs} = c_\beta \mathbf{m}_W R^{\widetilde{d}_g *}_{s1}(-s_W N_{i1} + 3c_W N_{i2}) - 3c_W \mathbf{m}_{d_g} R^{\widetilde{d}_g *}_{s2} N_{i3}$$

$$\mathcal{Z}^{25}_{ab} = \mathbf{N}_{a3}\mathbf{N}^*_{b3} - \mathbf{N}_{a4}\mathbf{N}^*_{b4}$$

$$\mathcal{W}^1_{nc} = (\mathbf{m}_{\widetilde{\chi}^-_c} C^L_{nc} + \mathbf{m}_{\widetilde{\chi}^0_n} C^R_{nc}), \qquad \mathcal{W}^2_{nc} = (\mathbf{m}_{\widetilde{\chi}^0_n} C^L_{nc} + \mathbf{m}_{\widetilde{\chi}^-_c} C^R_{nc})$$

$$\mathcal{W}^3_{nc} = (\mathbf{m}_{\widetilde{\chi}^-_c} D^L_{nc} + \mathbf{m}_{\widetilde{\chi}^0_n} D^R_{nc}), \qquad \mathcal{W}^4_{nc} = (\mathbf{m}_{\widetilde{\chi}^0_n} D^L_{nc} + \mathbf{m}_{\widetilde{\chi}^-_c} D^R_{nc})$$

$$\mathcal{W}^5_{c_1c_2} = (\mathbf{m}_{\widetilde{\chi}^-_{c_1}} \mathcal{Y}^1 + \mathbf{m}_{\widetilde{\chi}^-_{c_2}} \mathcal{Y}^{1*}), \qquad \mathcal{W}^6_{c_1c_2} = (\mathbf{m}_{\widetilde{\chi}^-_{c_1}} \mathcal{Y}^2 + \mathbf{m}_{\widetilde{\chi}^-_{c_2}} \mathcal{Y}^{2*})$$

$$\mathcal{W}^7_{c_1c_2} = (\mathbf{m}_{\widetilde{\chi}^-_{c_1}} \mathcal{Y}^3 - \mathbf{m}_{\widetilde{\chi}^-_{c_2}} \mathcal{Y}^{3*}), \qquad \mathcal{W}^8_{n_1n_2} = (\mathbf{m}_{\widetilde{\chi}^0_{n_1}} \mathcal{X}^1 - \mathbf{m}_{\widetilde{\chi}^0_{n_2}} \mathcal{X}^{1*})$$

$$\mathcal{W}^9_{g_1g_2s_1} = \sqrt{2} t_\beta \mathbf{m}^2_{d_{g_1}} U^*_{j2} R^{\widetilde{u}_{g_2}*}_{s_1 1}, \qquad \mathcal{W}^{10}_{g_1g_2s_1} = \sqrt{2} V_{j2} \mathbf{m}^2_{u_{g_1}} R^{\widetilde{d}_{g_2}}_{s_1 1}$$

$$\mathcal{T}^1 = \mathcal{T}^2 = \mathcal{T}^3 = \mathcal{T}^4 = \alpha/(8\sqrt{2} c_W \pi s^2_W), \qquad \mathcal{T}^5 = \mathcal{T}^6 = \alpha/(4\pi e^2)$$

$$\mathcal{T}^7 = \alpha e t_\beta (c_W N^*_{i2} - s_W N^*_{i1})/(8\mathbf{m}_W c_W \pi s^3_W), \qquad \mathcal{T}^8 = \alpha e t_\beta/(16 c_\beta c_W \mathbf{m}^2_W \pi s^3_W)$$

$$\mathcal{T}^9 = \alpha e \mathcal{K}_{g_2g_1}\mathcal{K}^*_{g_2g_1}/(16 c_W \mathbf{m}^3_W \pi s^2_\beta s^3_W t_\beta), \qquad \mathcal{T}^{10} = \alpha e \mathcal{K}_{g_1g_2}\mathcal{K}^*_{g_1g_2}/(16 c_W \mathbf{m}^3_W \pi s^2_\beta s^3_W)$$

$$\mathcal{T}^{11} = -\alpha \mathbf{m}_W [c_{2\beta} s_{\alpha+\beta}/(2c^2_W) + s_{\beta-\alpha}]/(8 c_W \pi s^2_W)$$

$$\mathcal{T}^{12} = -\alpha \mathbf{m}_W [c_{2\beta} s_{\alpha+\beta}/(2c^2_W) + s_{\beta-\alpha}]/(4\sqrt{2} \pi s^2_W)$$

$$\mathcal{T}^{13} = \alpha \mathbf{m}_W [c_{\beta-\alpha} - c_{2\beta} c_{\alpha+\beta}/(2c^2_W)]/(8 c_W \pi s^2_W)$$

$$\mathcal{T}^{14} = \alpha \mathbf{m}_W [c_{\beta-\alpha} - c_{2\beta} c_{\alpha+\beta}/(2c^2_W)]/(4\sqrt{2} \pi s^2_W)$$

$$\mathcal{T}^{15} = \alpha \mathbf{m}_W [c_{\beta-\alpha} - s_{2\beta} s_{\alpha+\beta}/(2c^2_W)]/(16 c_W \pi s^2_W)$$

$$\mathcal{T}^{16}=\alpha\mathbf{m}_W(c_{\beta-\alpha}-s_{2\beta}s_{\alpha+\beta}/c_W^2)/(8\sqrt{2}\pi s_W^2)$$

$$\mathcal{T}^{17}=\alpha\mathbf{m}_W[s_{\beta-\alpha}-s_{2\beta}c_{\alpha+\beta}/c_W^2]/(16c_W\pi s_W^2)$$

$$\mathcal{T}^{18}=\alpha\mathbf{m}_W[s_{\beta-\alpha}-s_{2\beta}c_{\alpha+\beta}/c_W^2]/(8\sqrt{2}\pi s_W^2)$$

$$\mathcal{T}^{19}=\alpha\mathbf{m}_W/(16c_W\pi s_W^2),\qquad \mathcal{T}^{20}=\alpha\mathbf{m}_W/(8\sqrt{2}\pi s_W^2)$$

$$\mathcal{T}^{21}=\alpha e/(16c_W\mathbf{m}_W\pi s_W^3),\qquad \mathcal{T}^{22}=\alpha e/(8\sqrt{2}c_\beta^2c_W\mathbf{m}_W^3\pi s_W^3)$$

$$\mathcal{T}^{23}=\alpha e\mathcal{K}_{g_2g_1}\mathcal{K}^*_{g_2g_1}/(16c_W\mathbf{m}_W^3\pi s_\beta^2s_W^3t_\beta),\qquad \mathcal{T}^{24}=\alpha e\mathcal{K}_{g_1g_2}\mathcal{K}^*_{g_1g_2}/(16c_W\mathbf{m}_W^3\pi s_\beta^2s_W^3)$$

$$\mathcal{T}^{25}=\alpha/(4c_W^2\pi s_W^2),\qquad \mathcal{T}^{26}=\alpha/(2\pi s_W^2)$$

$$\mathcal{T}^{27}=\alpha c_{2W}/(16\pi c_W^2s_W^2),\qquad \mathcal{T}^{28}=\alpha ec_{\beta-\alpha}/(8\sqrt{2}\pi s_W^3)$$

$$\mathcal{T}^{29}=\alpha es_{\beta-\alpha}/(8\sqrt{2}\pi s_W^3),\qquad \mathcal{T}^{30}=\alpha e/(8\sqrt{2}\pi s_W^3)$$

$$\mathcal{T}^{31}=-\alpha/(4\pi),\qquad \mathcal{T}^{32}=\alpha c_{2W}/(8\pi c_W^2s_W^2)$$

$$\mathcal{T}^{33}=\alpha ec_{\beta-\alpha}/(16c_W\pi s_W^2),\qquad \mathcal{T}^{34}=\alpha es_{\beta-\alpha}/(16c_W\pi s_W^2)$$

$$\mathcal{T}^{35}=\alpha e/(16c_W\pi s_W^2)$$

With the above abbreviations, we present the coefficients as following:

$$f_1^1=\mathcal{T}^1\sum_{c_1=1}^{2}\sum_{n_1=1}^{4}[b_0^1\mathcal{Y}^1_{c_1j}\mathcal{X}^1_{in_1}C^L_{n_1c_1}+c_2^1(\mathbf{m}_{\tilde{\chi}_i^0}\mathcal{W}^2_{n_1c_1}\mathcal{Y}^1_{c_1j}\mathcal{X}^{1*}_{in_1}-\mathbf{m}_{\tilde{\chi}_j^-}\mathcal{W}^1_{n_1c_1}\mathcal{Y}^{1*}_{jc_1}\mathcal{X}^1_{in_1}+\mathbf{m}^2_{H^-}\mathcal{Y}^1_{c_1j}\mathcal{X}^1_{in_1}C^L_{n_1c_1})$$

$$+c_0^1(\mathbf{m}_{\tilde{\chi}_{c_1}^-}\mathcal{W}^1_{n_1c_1}\mathcal{Y}^1_{c_1j}\mathcal{X}^1_{in_1}-\mathbf{m}_{\tilde{\chi}_{c_1}^-}\mathbf{m}_{\tilde{\chi}_j^-}\mathcal{Y}^{1*}_{jc_1}\mathcal{X}^1_{in_1}C^L_{n_1c_1}+\mathbf{m}_{\tilde{\chi}_{c_1}^-}\mathbf{m}_{\tilde{\chi}_i^0}\mathcal{Y}^1_{c_1j}C^R_{n_1c_1}\mathcal{X}^{1*}_{in_1})$$

$$+ c_1^1(\mathbf{m}^2_{\widetilde{\chi}_j^-}\mathcal{Y}^1_{c_1j}\mathcal{X}^1_{in_1}C^L_{n_1c_1} - \mathbf{m}_{\widetilde{\chi}_j^-}\mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{Y}^{1*}_{jc_1}C^R_{n_1c_1}\mathcal{X}^{1*}_{in_1} - \mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{W}^1_{n_1c_1}\mathcal{Y}^{1*}_{jc_1}\mathcal{X}^1_{in_1})]$$

$$f_2^1 = f_1^1(\mathcal{Y}^1_{c_1j} \leftrightarrow \mathcal{Y}^{1*}_{jc_1},\ \mathcal{X}^1_{in_1} \leftrightarrow \mathcal{X}^{1*}_{in_1},\ C^L_{n_1c_1} \leftrightarrow C^R_{n_1c_1},\ \mathcal{W}^1_{n_1c_1} \leftrightarrow \mathcal{W}^2_{n_1c_1})$$

$$f_1^2 = f_1^1(\mathcal{T}^1 \to \mathcal{T}^2,\ b_0^1 \to b_0^2,\ c^1_{(0,1,2)} \to c^2_{(0,1,2)},\ \mathcal{X}^1_{in_1} \to \mathcal{X}^2_{in_1},\ \mathcal{X}^{1*}_{in_1} \to \mathcal{X}^{2*}_{in_1},$$

$$\mathcal{Y}^1_{c_1j} \to \mathcal{Y}^2_{c_1j},\ \mathcal{Y}^{1*}_{jc_1} \to \mathcal{Y}^{2*}_{jc_1})$$

$$f_2^2 = f_1^2(\mathcal{Y}^2_{c_1j} \leftrightarrow \mathcal{Y}^{2*}_{jc_1},\ \mathcal{X}^2_{in_1} \leftrightarrow \mathcal{X}^{2*}_{in_1},\ C^L_{n_1c_1} \leftrightarrow C^R_{n_1c_1},\ \mathcal{W}^1_{n_1c_1} \leftrightarrow \mathcal{W}^2_{n_1c_1})$$

$$f_1^3 = f_1^1(\mathcal{T}^1 \to \mathcal{T}^3,\ b_0^1 \to b_0^3,\ c^1_{(0,1,2)} \to c^3_{(0,1,2)},\ \mathcal{X}^1_{in_1} \to \mathcal{X}^3_{in_1},\ \mathcal{X}^{1*}_{in_1} \to -\mathcal{X}^{3*}_{in_1},$$

$$\mathcal{Y}^1_{c_1j} \to \mathcal{Y}^3_{c_1j},\ \mathcal{Y}^{1*}_{jc_1} \to -\mathcal{Y}^{3*}_{jc_1})$$

$$f_2^3 = f_1^3(\mathcal{Y}^3_{c_1j} \leftrightarrow \mathcal{Y}^{3*}_{jc_1},\ \mathcal{X}^3_{in_1} \leftrightarrow \mathcal{X}^{3*}_{in_1},\ C^L_{n_1c_1} \leftrightarrow C^R_{n_1c_1},\ \mathcal{W}^1_{n_1c_1} \leftrightarrow \mathcal{W}^2_{n_1c_1})$$

$$f_1^4 = f_1^3(\mathcal{T}^3 \to \mathcal{T}^4,\ b_0^3 \to b_0^4,\ c^3_{(0,1,2)} \to c^4_{(0,1,2)},\ \mathcal{X}^3_{in_1} \to \mathcal{X}^4_{in_1},\ \mathcal{X}^{3*}_{in_1} \to \mathcal{X}^{4*}_{in_1},$$

$$\mathcal{Y}^3_{c_1j} \to \mathcal{Y}^4_{c_1j},\ \mathcal{Y}^{3*}_{jc_1} \to \mathcal{Y}^{4*}_{jc_1})$$

$$f_2^4 = f_1^4(\mathcal{Y}^4_{c_1j} \leftrightarrow \mathcal{Y}^{4*}_{jc_1},\ \mathcal{X}^4_{in_1} \leftrightarrow \mathcal{X}^{4*}_{in_1},\ C^L_{n_1c_1} \leftrightarrow C^R_{n_1c_1},\ \mathcal{W}^1_{n_1c_1} \leftrightarrow \mathcal{W}^2_{n_1c_1})$$

$$f_1^5 = f_1^4(T^4 \to T^5,\ b_0^4 \to b_0^5,\ c^4_{(0,1,2)} \to c^5_{(0,1,2)},\ \mathbf{m}_{\widetilde{\chi}^0_{n_1}} \to m_{\widetilde{\chi}^-_{c_1}},\ \mathcal{X}^4_{in_1} \to C^{L*}_{ic_1},\ \mathcal{X}^{4*}_{in_1} \to -C^{R*}_{ic_1},$$

$$\mathcal{Y}^4_{c_1j} \to C^R_{n_1j},\ \mathcal{Y}^{4*}_{jc_1} \to -C^L_{n_1j},\ \mathcal{W}^1_{n_1c_1} \leftrightarrow \mathcal{W}^2_{n_1c_1})$$

$$f_2^5 = f_1^5(L \leftrightarrow R,\ \mathcal{W}^1_{n_1c_1} \leftrightarrow \mathcal{W}^2_{n_1c_1})$$

$$f_1^6 = f_1^5(\mathcal{T}^5 \to \mathcal{T}^6,\ b_0^5 \to b_0^6,\ c^5_{(0,1,2)} \to c^6_{(0,1,2)},\ C^{L*}_{ic_1} \to -C^{L*}_{ic_1},\ C^L_{ic_1} \to -C^L_{ic_1})$$

$$f_2^6 = f_1^6(L \leftrightarrow R)$$

$$f_1^7 = -\mathcal{T}^7 \sum_{g_1=1}^{3} \mathbf{m}_{e_{g_1}}^2 \mathbf{m}_{\widetilde{\chi}_i^0} \left[V_{j1}(c_0^7 + c_2^7) + c_1^7 \mathbf{m}_{\widetilde{\chi}_j^-} U_{j2}^* / (\sqrt{2} c_\beta \mathbf{m}_W) \right]$$

$$f_2^7 == \mathcal{T}^7 \sum_{g_1=1}^{3} \mathbf{m}_{e_{g_1}}^2 \left(\frac{U_{j2}^*}{\sqrt{2} c_\beta \mathbf{m}_W} (b_0^7 + m_{H^-}^2 c_2^7 + m_{\widetilde{\chi}_j^-}^2 c_1^7 + c_0^7 \mathbf{m}_{e_{g_1}}^2) + \mathbf{m}_{\widetilde{\chi}_j^-} V_{j1}(c_0^7 + c_1^7 + c_2^7) \right)$$

$$f_1^8 = \mathcal{T}^8 \sum_{g_1=1}^{3} \sum_{s_1=1}^{2} (c_1^8 + c_2^8) \mathbf{m}_{\widetilde{\chi}_j^-} m_{e_{g_1}}^2 \mathcal{Y}_{g_1 s_1}^8 \mathcal{X}_{g_1 s_1}^8 - \mathbf{m}_{\widetilde{\chi}_j^-} m_{e_{g_1}} m_{\widetilde{\chi}_i^0} \mathcal{Y}_{g_1 s_1}^8 \mathcal{Z}_{g_1 s_1}^8$$

$$f_2^8 = \mathcal{T}^8 \sum_{g_1=1}^{3} \sum_{s_1=1}^{2} (b_0^8 + c_2^8 m_{\widetilde{\chi}_j^-}^2 + m_{H^-}^2) \mathbf{m}_{e_{g_1}} \mathcal{Y}_{g_1 s_1}^8 \mathcal{Z}_{g_1 s_1}^8 - c_1^8 m_{e_{g_1}}^2 \mathbf{m}_{\widetilde{\chi}_i^0} \mathcal{Y}_{g_1 s_1}^8 \mathcal{X}_{g_1 s_1}^8$$

$$f_1^9 = \sum_{g_1=1}^{3} \sum_{g_2=1}^{3} \sum_{s_1=1}^{2} \mathcal{T}^9 [\mathbf{m}_{u_{g_2}} \mathcal{X}_{g_2 s_1}^9 \mathcal{Y}_{g_2 s_1}^9 (b_0^9 + c_0^9 (\mathbf{m}_{u_{g_2}}^2 + t_\beta^2 \mathbf{m}_{d_{g_1}}^2) + c_1^9 \mathbf{m}_{H^-}^2 + c_2^9 \mathbf{m}_{\widetilde{\chi}_i^0}^2)$$

$$- t_\beta^2 \mathcal{W}_{g_1 g_2 s_1}^9 \mathbf{m}_{\widetilde{\chi}_j^-} (\mathbf{m}_{u_{g_2}} \mathcal{Y}_{g_2 s_1}^9 (c_0^9 + c_1^9 / s_\beta^2) + c_2^9 \mathbf{m}_{\widetilde{\chi}_i^0} \mathcal{Z}_{g_2 s_1}^9)$$

$$+ \mathbf{m}_{\widetilde{\chi}_i^0} \mathcal{X}_{g_2 s_1}^9 \mathcal{Z}_{g_2 s_1}^9 (c_0^9 \mathbf{m}_{u_{g_2}}^2 + (c_1^9 + c_2^9)(\mathbf{m}_{u_{g_2}}^2 + t_\beta^2 \mathbf{m}_{d_{g_1}}^2))]$$

$$f_2^9 = \sum_{g_1=1}^{3} \sum_{g_2=1}^{3} \sum_{s_1=1}^{2} \mathcal{T}^9 [\mathcal{W}_{g_1 g_2 s_1}^9 \mathcal{Z}_{g_2 s_1}^9 t_\beta^2 (b_0^9 + c_0^9 \mathbf{m}_{u_{g_2}}^2 / s_\beta^2 + c_2^9 \mathbf{m}_{\widetilde{\chi}_i^0}^2 + c_1^9 \mathbf{m}_{H^-}^2)$$

$$+ \mathcal{W}_{g_1 g_2 s_1}^9 \mathcal{Y}_{g_2 s_1}^9 \mathbf{m}_{\widetilde{\chi}_i^0} \mathbf{m}_{u_{g_2}} ((c_2^9 + c_1^9)/c_\beta^2 + c_0^9 t_\beta^2) - \mathcal{X}_{g_2 s_1}^9 \mathbf{m}_{\widetilde{\chi}_j^-} (c_2^9 \mathbf{m}_{\widetilde{\chi}_i^0} \mathbf{m}_{u_{g_2}} \mathcal{Y}_{g_2 s_1}^9$$

$$+ ((c_0^9 + c_1^9) \mathbf{m}_{u_{g_2}}^2 + c_1^9 \mathbf{m}_{d_{g_1}}^2 t_\beta^2) \mathcal{Z}_{g_2 s_1}^9)]$$

$$f_1^{10} = \sum_{g_1=1}^{3} \sum_{g_2=1}^{3} \sum_{s_1=1}^{2} \mathcal{T}^{10} [\mathcal{W}_{g_1 g_2 s_1}^{10} \mathcal{Z}_{g_2 s_1}^{10} (b_0^{10} + (\mathbf{m}_{u_{g_1}}^2 + t_\beta^2 \mathbf{m}_{d_{g_2}}^2) c_0^{10} + \mathbf{m}_{\widetilde{\chi}_j^-}^2 c_2^{10} + \mathbf{m}_{H^-}^2 c_1^{10})$$

$$- \mathcal{X}_{g_2 s_1}^{10} \mathcal{Z}_{g_2 s_1}^{10} \mathbf{m}_{\widetilde{\chi}_j^-}^2 ((c_2^{10} + c_1^{10}) t_\beta (\mathbf{m}_{u_{g_1}}^2 + t_\beta^2 \mathbf{m}_{d_{g_2}}^2) + c_0^{10} \mathbf{m}_{u_{g_1}}^2)$$

$$+ \mathcal{Y}_{g_2 s_1}^{10} \mathbf{m}_{\widetilde{\chi}_i^0}^2 ((c_0^{10} t_\beta^2 + c_1^{10} (1 + t_\beta^2)) \mathcal{W}_{g_1 g_2 s_1}^{10} - \mathcal{X}_{g_2 s_1}^{10} c_2^{10} \mathbf{m}_{\widetilde{\chi}_j^-} t_\beta^3)]$$

$$f_2^{10} = \sum_{g_1=1}^{3}\sum_{g_2=1}^{3}\sum_{s_1=1}^{2}\mathcal{T}^{10}[\mathcal{X}^{10}_{g_2s_1}\mathcal{Y}^{10}_{g_2s_1}(t_\beta^3(b_0^{10}+c_1^{10}\mathbf{m}^2_{H^-}+c_2^{10}\mathbf{m}^2_{\widetilde{\chi}_j^-})+(1+t_\beta^2)\mathbf{m}^2_{u_{g_1}}c_0^{10})$$

$$-\mathcal{W}^{10}_{g_1g_2s_1}\mathcal{Y}^{10}_{g_2s_1}\mathbf{m}_{\widetilde{\chi}_j^-}((1+t_\beta^2)(c_1^{10}+c_2^{10})+c_0^{10}t_\beta^2)\mathcal{Z}^{10}_{g_2s_1}\mathbf{m}_{\widetilde{\chi}_i^0}(\mathcal{X}^{10}_{g_2s_1}t_\beta(c_0^{10}\mathbf{m}^2_{u_{g_1}}$$

$$+c_1^{10}(\mathbf{m}^2_{u_{g_1}}+t_\beta^2\mathbf{m}^2_{d_{g_2}}))-c_2^{10}\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{W}^{10}_{g_1g_2s_1})]$$

$$f_1^{11} = \mathcal{T}^{11}\sum_{n_1=1}^{4}[c_1^{11}\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{X}^1_{in_1}C^L_{n_1j}+c_0^{11}\mathcal{X}^1_{in_1}\mathcal{W}^2_{n_1j}+c_2^{11}(\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{X}^1_{in_1}C^L_{n_1j}-\mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{X}^{1*}_{in_1}C^R_{n_1j})]$$

$$f_2^{11} = f_1^{11}(C^L_{n_1j}\leftrightarrow C^R_{n_1j},\ \mathcal{X}^1_{in_1}\leftrightarrow\mathcal{X}^{1*}_{in_1},\ \mathcal{W}^2_{n_1j}\to\mathcal{W}^1_{n_1j})$$

$$f_1^{12} = \mathcal{T}^{12}\sum_{c_1=1}^{2}[c_1^{12}\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{Y}^{1*}_{jc_1}C^R_{ic_1}+c_0^{12}\mathcal{W}^5_{c_1j}C^R_{ic_1}+c_2^{12}(\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{Y}^{1*}_{jc_1}C^R_{ic_1}-\mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{Y}^1_{c_1j}C^L_{ic_1})]$$

$$f_2^{12} = f_1^{12}(C^L_{ic_1}\leftrightarrow C^R_{ic_1},\ \mathcal{Y}^1_{c_1j}\leftrightarrow\mathcal{Y}^{1*}_{jc_1},\ \mathcal{W}^5_{c_1j}\to\mathcal{W}^5_{jc_1})$$

$$f_1^{13} = \mathcal{T}^{13}\sum_{n_1=1}^{4}[c_1^{13}\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{X}^2_{in_1}C^L_{n_1j}+c_0^{13}\mathcal{X}^2_{in_1}\mathcal{W}^2_{n_1j}+c_2^{13}(\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{X}^2_{in_1}C^L_{n_1j}+\mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{X}^{2*}_{in_1}C^R_{n_1j})]$$

$$f_2^{13} = f_1^{13}(C^L_{n_1j}\leftrightarrow C^R_{n_1j},\ \mathcal{X}^2_{in_1}\leftrightarrow\mathcal{X}^{2*}_{in_1},\ \mathcal{W}^2_{n_1j}\to\mathcal{W}^1_{n_1j})$$

$$f_1^{14} = \mathcal{T}^{14}\sum_{c_1=1}^{2}[c_1^{14}\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{Y}^{2*}_{jc_1}C^R_{ic_1}+c_0^{14}\mathcal{W}^5_{c_1j}C^R_{ic_1}+c_2^{14}(\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{Y}^{2*}_{jc_1}C^R_{ic_1}-\mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{Y}^2_{c_1j}C^L_{ic_1})]$$

$$f_2^{14} = f_1^{14}(C^L_{ic_1}\leftrightarrow C^R_{ic_1},\ \mathcal{Y}^2_{c_1j}\leftrightarrow\mathcal{Y}^{2*}_{jc_1},\ \mathcal{W}^6_{c_1j}\to\mathcal{W}^6_{jc_1})$$

$$f_1^{15} = \mathcal{T}^{15}\sum_{n_1=1}^{4}[c_1^{15}\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{X}^1_{in_1}D^L_{n_1j}+c_0^{15}\mathcal{X}^1_{in_1}\mathcal{W}^3_{n_1j}+c_2^{15}(\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{X}^1_{in_1}D^L_{n_1j}-\mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{X}^{1*}_{in_1}D^R_{n_1j})]$$

$$f_2^{15} = f_1^{15}(D^L_{n_1j}\leftrightarrow D^R_{n_1j},\ \mathcal{X}^1_{in_1}\leftrightarrow\mathcal{X}^{1*}_{in_1},\ \mathcal{W}^3_{n_1j}\to\mathcal{W}^4_{n_1j})$$

$$f_1^{16} = \mathcal{T}^{16}\sum_{c_1=1}^{2}[c_1^{16}\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{Y}^{1*}_{jc_1}D^R_{ic_1}+c_0^{16}\mathcal{W}^5_{c_1j}D^R_{ic_1}+c_2^{16}(\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{Y}^{1*}_{jc_1}D^R_{ic_1}-\mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{Y}^1_{c_1j}D^L_{ic_1})]$$

$$f_2^{16} = f_1^{16}(D^L_{ic_1}\leftrightarrow D^R_{ic_1},\ \mathcal{Y}^1_{c_1j}\leftrightarrow\mathcal{Y}^{1*}_{jc_1},\ \mathcal{W}^5_{c_1j}\to\mathcal{W}^5_{jc_1})$$

$$f_1^{17} = \mathcal{T}^{17} \sum_{n_1=1}^{4} [c_1^{17} \mathbf{m}_{\widetilde{\chi}_j^-} \mathcal{X}_{in_1}^2 D_{n_1j}^L + c_0^{17} \mathcal{X}_{in_1}^2 \mathcal{W}_{n_1j}^3 + c_2^{17} (\mathbf{m}_{\widetilde{\chi}_j^-} \mathcal{X}_{in_1}^2 D_{n_1j}^L - \mathbf{m}_{\widetilde{\chi}_i^0} \mathcal{X}_{in_1}^{2*} D_{n_1j}^R)]$$

$$f_2^{17} = f_1^{17} (D_{n_1j}^L \leftrightarrow D_{n_1j}^R,\ \mathcal{X}_{in_1}^2 \leftrightarrow \mathcal{X}_{in_1}^{2*},\ \mathcal{W}_{n_1j}^3 \to \mathcal{W}_{n_1j}^4)$$

$$f_1^{18} = \mathcal{T}^{18} \sum_{c_1=1}^{2} [c_1^{18} \mathbf{m}_{\widetilde{\chi}_j^-} \mathcal{Y}_{jc_1}^{2*} D_{ic_1}^R + c_0^{18} \mathcal{W}_{c_1j}^5 D_{ic_1}^R + c_2^{18} (\mathbf{m}_{\widetilde{\chi}_j^-} \mathcal{Y}_{jc_1}^{2*} D_{ic_1}^R - \mathbf{m}_{\widetilde{\chi}_i^0} \mathcal{Y}_{c_1j}^2 D_{ic_1}^L)]$$

$$f_2^{18} = f_1^{18} (D_{ic_1}^L \leftrightarrow D_{ic_1}^R,\ \mathcal{Y}_{c_1j}^2 \leftrightarrow \mathcal{Y}_{jc_1}^{2*},\ \mathcal{W}_{c_1j}^6 \to \mathcal{W}_{jc_1}^6)$$

$$f_1^{19} = \mathcal{T}^{19} \sum_{n_1=1}^{4} [c_1^{19} \mathbf{m}_{\widetilde{\chi}_j^-} \mathcal{X}_{in_1}^3 D_{n_1j}^L + c_0^{19} \mathcal{X}_{in_1}^3 \mathcal{W}_{n_1j}^3 + c_2^{19} (\mathbf{m}_{\widetilde{\chi}_j^-} \mathcal{X}_{in_1}^3 D_{n_1j}^L + \mathbf{m}_{\widetilde{\chi}_i^0} \mathcal{X}_{in_1}^{3*} D_{n_1j}^R)]$$

$$f_2^{19} = -f_1^{19} (D_{n_1j}^L \leftrightarrow D_{n_1j}^R,\ \mathcal{X}_{in_1}^3 \leftrightarrow \mathcal{X}_{in_1}^{3*},\ \mathcal{W}_{n_1j}^3 \to \mathcal{W}_{n_1j}^4)$$

$$f_1^{20} = \mathcal{T}^{20} \sum_{c_1=1}^{2} [c_1^{20} \mathbf{m}_{\widetilde{\chi}_j^-} \mathcal{Y}_{jc_1}^{3*} D_{ic_1}^R + c_0^{20} \mathcal{W}_{c_1j}^5 D_{ic_1}^R + c_2^{20} (\mathbf{m}_{\widetilde{\chi}_j^-} \mathcal{Y}_{jc_1}^{3*} D_{ic_1}^R + \mathbf{m}_{\widetilde{\chi}_i^0} \mathcal{Y}_{c_1j}^3 D_{ic_1}^L)]$$

$$f_2^{20} = -f_1^{20} (D_{ic_1}^L \leftrightarrow D_{ic_1}^R,\ \mathcal{Y}_{c_1j}^3 \leftrightarrow \mathcal{Y}_{jc_1}^{3*},\ \mathcal{W}_{c_1j}^6 \to \mathcal{W}_{jc_1}^6)$$

$$f_1^{21} = \mathcal{T}^{21} \sum_{g_1=1}^{3} \sum_{s_1=1}^{2} (c_0^{21} + c_1^{21} + c_2^{22}) \mathbf{m}_{\widetilde{\chi}_j^-} \mathcal{Y}_{js_1}^8 \mathcal{X}_{g_1s_1}^{21}$$

$$f_2^{21} = -\mathcal{T}^{21} \sum_{g_1=1}^{3} \sum_{s_1=1}^{2} c_2^{21} \mathbf{m}_{\widetilde{\chi}_i^0} \mathcal{Y}_{js_1}^8 \mathcal{X}_{g_1s_1}^{21}$$

$$f_1^{22} = \mathcal{T}^{22} \sum_{g_1=1}^{3} \sum_{s_1=1}^{2} [c_1^{22} \mathbf{m}_{\widetilde{\chi}_j^-} \mathbf{m}_{e_{g_1}} U_{j2}^* \mathcal{X}_{g_1s_1}^{21} \mathcal{Z}_{g_1s_1}^8 + (c_0^{22} \mathbf{m}_{e_{g_1}} \mathcal{Z}_{g_1s_1}^8 + c_2^{22} \mathbf{m}_{\widetilde{\chi}_i^0} \mathcal{X}_{g_1s_1}^8) \mathcal{X}_{g_1s_1}^{21} V_{j1} \sqrt{2} c_\beta \mathbf{m}_W]$$

$$f_2^{22} = \mathcal{T}^{22} \sum_{g_1=1}^{3} \sum_{s_1=1}^{2} [c_1^{22} \mathbf{m}_{\widetilde{\chi}_j^-} V_{j1} \mathcal{X}_{g_1s_1}^{21} \mathcal{X}_{g_1s_1}^8 \sqrt{2} c_\beta \mathbf{m}_W + (c_0^{22} \mathbf{m}_{e_{g_1}} \mathcal{X}_{g_1s_1}^8 + c_2^{22} \mathbf{m}_{\widetilde{\chi}_i^0} \mathcal{Z}_{g_1s_1}^8) \mathbf{m}_{e_{g_1}} U_{j2}^* \mathcal{X}_{g_1s_1}^{21}]$$

$$f_1^{23} = \sum_{g_1=1}^{3} \sum_{g_2=1}^{3} \sum_{s_1=1}^{2} \sum_{s_2=1}^{2} \mathcal{T}^{23} \mathcal{X}^{23} [c_1^{23} \mathbf{m}_{\widetilde{\chi}_j^-} \mathcal{X}_{g_1s_1}^{10} \mathcal{Z}_{g_2s_2}^{9*} t_\beta - (c_0^{23} \mathbf{m}_{u_{g_2}} \mathcal{Z}_{g_2s_2}^{9*} + c_2^{23} \mathbf{m}_{\widetilde{\chi}_i^0} \mathcal{Y}_{g_2s_2}^{9*}) \mathbf{m}_{u_{g_2}} R_{s_11}^{\widetilde{d}_{g_1}} V_{j2} \sqrt{2}]$$

$$f_2^{23} = \sum_{g_1=1}^{3} \sum_{g_2=1}^{3} \sum_{s_1=1}^{2} \sum_{s_2=1}^{2} \mathcal{T}^{23} \mathcal{X}^{23} [(c_0^{23} \mathbf{m}_{u_{g_2}} \mathcal{Y}_{g_2s_2}^{9*} + c_2^{23} \mathbf{m}_{\widetilde{\chi}_i^0} \mathcal{Z}_{g_2s_2}^{9*}) \mathcal{X}_{g_1s_1}^{10} t_\beta - c_1^{23} \mathbf{m}_{\widetilde{\chi}_j^-} \mathbf{m}_{u_{g_2}} R_{s_11}^{\widetilde{d}_{g_1}} V_{j2} \mathcal{Y}_{g_2s_2}^{9*} \sqrt{2}]$$

$$f_1^{24} = \sum_{g_1=1}^{3}\sum_{g_2=1}^{3}\sum_{s_1=1}^{2}\sum_{s_2=1}^{2} \mathcal{T}^{24}\mathcal{X}^{23}[c_1^{24}\mathbf{m}_{\widetilde{\chi}_j^-}\mathbf{m}_{d_{g_2}}U_{j2}^* R_{s_1 1}^{\widetilde{u}_{g_1}*}\sqrt{2}t_\beta \mathcal{Y}_{g_2 s_2}^{10*} + (c_0^{24}\mathbf{m}_{d_{g_2}}\mathcal{Y}_{g_2 s_2}^{10*} - c_2^{24}\mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{Z}_{g_2 s_2}^{10*})\mathcal{X}_{g_1 s_1}^{9}]$$

$$f_2^{24} = \sum_{g_1=1}^{3}\sum_{g_2=1}^{3}\sum_{s_1=1}^{2}\sum_{s_2=1}^{2} \mathcal{T}^{24}\mathcal{X}^{23}[\mathbf{m}_{d_{g_2}}U_{j2}^* R_{s_1 1}^{\widetilde{u}_{g_1}*}\sqrt{2}t_\beta (c_2^{24}\mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{Y}_{g_2 s_2}^{10*} - c_0^{24}\mathbf{m}_{d_{g_2}}\mathcal{Z}_{g_2 s_2}^{10*}) + c_1^{24}\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{X}_{g_1 s_1}^{9}\mathcal{Z}_{g_2 s_2}^{10*}]$$

$$f_1^{25} = \mathcal{T}^{25}\sum_{c_1=1}^{2}\sum_{n_1=1}^{4}[-2b_0^{25}\mathcal{Y}_{c_1 j}^{25}C_{n_1 c_1}^{R}\mathcal{Z}_{in_1}^{25} - c_2^{25}(\mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{Y}_{c_1 j}^{25}\mathcal{Z}_{in_1}^{25*}\mathcal{W}_{n_1 c_1}^{1} + \mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{X}_{jc_1}^{25}\mathcal{Z}_{in_1}^{25}\mathcal{W}_{n_1 c_1}^{2}$$

$$+ 2\mathbf{m}_{H^-}^2\mathcal{Y}_{c_1 j}^{25}C_{n_1 c_1}^{R}\mathcal{Z}_{in_1}^{25}) - c_1^{25}(\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{X}_{jc_1}^{25}\mathcal{Z}_{in_1}^{25}\mathcal{W}_{n_1 c_1}^{2} + (\mathbf{m}_{H^-}^2 + \mathbf{m}_{\widetilde{\chi}_j^-}^2 - \mathbf{m}_{\widetilde{\chi}_i^0}^2)\mathcal{Y}_{c_1 j}^{25}C_{n_1 c_1}^{R}\mathcal{Z}_{in_1}^{25})$$

$$- c_0^{25}(\mathbf{m}_{\widetilde{\chi}_{c_1}^-}\mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{Y}_{c_1 j}^{25}\mathcal{Z}_{in_1}^{25*}C_{n_1 c_1}^{L} + \mathbf{m}_{\widetilde{\chi}_{c_1}^-}\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{X}_{jc_1}^{25}C_{n_1 c_1}^{R}\mathcal{Z}_{in_1}^{25} + 2\mathbf{m}_{\widetilde{\chi}_{c_1}^-}\mathcal{Y}_{c_1 j}^{25}\mathcal{Z}_{in_1}^{25}\mathcal{W}_{n_1 c_1}^{2})]$$

$$f_2^{25} = -f_1^{25}(L \leftrightarrow R,\ \mathcal{Y}_{c_1 j}^{25} \leftrightarrow \mathcal{X}_{jc_1}^{25},\ \mathcal{Z}_{in_1}^{25} \leftrightarrow \mathcal{Z}_{in_1}^{25*},\ \mathcal{W}_{n_1 c_1}^{1} \leftrightarrow \mathcal{W}_{n_1 c_1}^{2},\ )$$

$$f_1^{26} = \mathcal{T}^{26}\sum_{c_1=1}^{2}\sum_{n_1=1}^{4}[2b_0^{26}\mathcal{Y}_{c_1 i}^{26}C_{n_1 c_1}^{R}\mathcal{Y}_{jn_1}^{26*} + c_1^{26}(\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{Y}_{c_1 i}^{26}\mathcal{X}_{c_1 i}^{26*}\mathcal{W}_{n_1 c_1}^{1} + (\mathbf{m}_{H^-}^2 + \mathbf{m}_{\widetilde{\chi}_j^-}^2 - \mathbf{m}_{\widetilde{\chi}_i^0}^2)$$

$$\times \mathcal{Y}_{c_1 i}^{26}\mathcal{Y}_{jn_1}^{26*}C_{n_1 c_1}^{R}) + c_2^{26}(\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{Y}_{c_1 i}^{26}\mathcal{X}_{c_1 i}^{26*}\mathcal{W}_{n_1 c_1}^{1} + 2\mathbf{m}_{H^-}^2\mathcal{Y}_{c_1 i}^{26}C_{n_1 c_1}^{R}\mathcal{Y}_{jn_1}^{26*} - \mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{X}_{jn_1}^{26}\mathcal{Y}_{jn_1}^{26*}\mathcal{W}_{n_1 c_1}^{2})$$

$$+ c_0^{26}(2\mathbf{m}_{\widetilde{\chi}_{n_1}^0}\mathcal{Y}_{c_1 i}^{26}\mathcal{Y}_{jn_1}^{26*}\mathcal{W}_{n_1 c_1}^{1} + \mathbf{m}_{\widetilde{\chi}_j^-}\mathbf{m}_{\widetilde{\chi}_{n_1}^0}\mathcal{Y}_{c_1 i}^{26}\mathcal{X}_{c_1 i}^{26*}C_{n_1 c_1}^{R} - \mathbf{m}_{\widetilde{\chi}_i^0}\mathbf{m}_{\widetilde{\chi}_{n_1}^0}\mathcal{X}_{jn_1}^{26}\mathcal{Y}_{jn_1}^{26*}C_{n_1 c_1}^{L})]$$

$$f_2^{26} = f_1^{26}(L \leftrightarrow R,\ \mathcal{W}_{n_1 c_1}^{1} \leftrightarrow \mathcal{W}_{n_1 c_1}^{2},\ \mathcal{X}_{jn_1}^{26} \leftrightarrow \mathcal{Y}_{c_1 i}^{26},\ \mathcal{X}_{c_1 i}^{26*} \leftrightarrow \mathcal{Y}_{jn_1}^{26*})$$

$$f_1^{27} = \mathcal{T}^{27}\sum_{n_1=1}^{4}[-b_0^{27}C_{n_1 j}^{R}\mathcal{Z}_{in_1}^{25} + c_1^{27}\mathbf{m}_{\widetilde{\chi}_j^-}C_{n_1 j}^{L}(\mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{Z}_{in_1}^{25*} - \mathbf{m}_{\widetilde{\chi}_{n_1}^0}\mathcal{Z}_{in_1}^{25})$$

$$+ c_2^{27}(\mathbf{m}_{H^-}^2 C_{n_1 j}^{R}\mathcal{Z}_{in_1}^{25} - \mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{Z}_{in_1}^{25*}\mathcal{W}_{n_1 j}^{1} - \mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{Z}_{in_1}^{25}\mathcal{W}_{n_1 j}^{2})$$

$$+ c_0^{27}(\mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{Z}_{in_1}^{25*}\mathcal{W}_{n_1 j}^{1} + \mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{Z}_{in_1}^{25}\mathcal{W}_{n_1 j}^{2} - \mathbf{m}_{H^-}^2 C_{n_1 j}^{R}\mathcal{Z}_{in_1}^{25})]$$

$$f_2^{27} = f_2^{27}(L \leftrightarrow R,\ \mathcal{Z}_{in_1}^{25} \leftrightarrow -\mathcal{Z}_{in_1}^{25*},\ \mathcal{W}_{n_1 j}^{1} \leftrightarrow \mathcal{W}_{n_1 j}^{2})$$

$$f_1^{28} = \mathcal{T}^{28}\sum_{c_1=1}^{2}[(b_0^{28} + c_0^{28}\mathbf{m}_{h^0}^2 - c_2^{28}\mathbf{m}_{H^-}^2)\mathcal{Y}_{c_1 j}^{1}\mathcal{X}_{c_1 i}^{26} + (c_2^{28} - c_0^{28})(\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{X}_{c_1 i}^{26}\mathcal{W}_{jc_1}^{5}$$

$$- \mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{Y}_{c_1 i}^{26}\mathcal{W}_{c_1 j}^{5}) + c_1^{28}\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{Y}_{j c_1}^{1*}](\mathbf{m}_{\widetilde{\chi}_{c_1}^-}\mathcal{X}_{c_1 i}^{26} + \mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{Y}_{c_1 i}^{26})$$

$$f_2^{28} = f_1^{28}(\mathcal{Y}_{c_1 j}^{1} \leftrightarrow \mathcal{Y}_{j c_1}^{1*},\ \mathcal{X}_{c_1 i}^{26} \leftrightarrow \mathcal{Y}_{c_1 i}^{26})$$

$$f_1^{29} = f_1^{28}(h^0 \to H^0,\ \mathcal{T}^{28} \to \mathcal{T}^{29},\ b_0^{28} \to b_0^{29},\ c_{(0,1,2)}^{28} \to c_{(0,1,2)}^{29},\ \mathcal{Y}_{c_1 j}^{1} \to \mathcal{Y}_{c_1 j}^{2},$$

$$\mathcal{Y}_{c_1 j}^{1*} \to \mathcal{Y}_{c_1 j}^{2*},\ \mathcal{W}^5 \to \mathcal{W}^6)$$

$$f_2^{29} = f_2^{28}(h^0 \to H^0,\ \mathcal{T}^{28} \to \mathcal{T}^{29},\ b_0^{28} \to b_0^{29},\ c_{(0,1,2)}^{28} \to c_{(0,1,2)}^{29},\ \mathcal{Y}_{c_1 j}^{1} \to \mathcal{Y}_{c_1 j}^{2},$$

$$\mathcal{Y}_{c_1 j}^{1*} \to \mathcal{Y}_{c_1 j}^{2*},\ \mathcal{W}^5 \to \mathcal{W}^6)$$

$$f_1^{30} = -f_1^{29}(H^0 \to A^0,\ \mathcal{T}^{29} \to \mathcal{T}^{30},\ b_0^{29} \to b_0^{30},\ c_{(0,1,2)}^{29} \to c_{(0,1,2)}^{30},\ \mathcal{Y}_{c_1 j}^{1} \to \mathcal{Y}_{c_1 j}^{2},$$

$$\mathcal{Y}_{c_1 j}^{1*} \to -\mathcal{Y}_{c_1 j}^{2*},\ \mathcal{W}^5 \to \mathcal{W}^6)$$

$$f_2^{30} = -f_2^{29}(H^0 \to A^0,\ \mathcal{T}^{29} \to \mathcal{T}^{30},\ b_0^{29} \to b_0^{30},\ c_{(0,1,2)}^{29} \to c_{(0,1,2)}^{30},\ \mathcal{Y}_{c_1 j}^{1} \to \mathcal{Y}_{c_1 j}^{2},$$

$$\mathcal{Y}_{c_1 j}^{1*} \to -\mathcal{Y}_{c_1 j}^{2*},\ \mathcal{W}^5 \to \mathcal{W}^6)$$

$$f_1^{31} = \mathcal{T}^{31}[(c_2^{31} + 2c_0^{31} + 2c_1^{31})(\mathbf{m}_{H^-}^2 + \mathbf{m}_{\widetilde{\chi}_j^-}^2 - \mathbf{m}_{\widetilde{\chi}_i^0}^2)C_{ij}^R + (b_0^{31} + 2c_2^{31}\mathbf{m}_{H^-}^2)C_{ij}^R - 2c_1^{31}\mathbf{m}_{\widetilde{\chi}_j^-}\mathbf{m}_{\widetilde{\chi}_i^0}C_{ij}^L]$$

$$f_2^{31} = f_1^{31}(L \leftrightarrow R)$$

$$f_1^{32} = \mathcal{T}^{32}\sum_{c_1=1}^{2}[b_0^{32}\mathcal{Y}_{c_1 j}^{25}C_{ic_1}^R + c_1^{32}(\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{X}_{c_1 j}^{25}\mathcal{W}_{ic_1}^2 + (2\mathbf{m}_{H^-}^2 + \mathbf{m}_{\widetilde{\chi}_j^-}^2 - 2\mathbf{m}_{\widetilde{\chi}_i^0}^2)\mathcal{Y}_{c_1 j}^{25}C_{ic_1}^R + \mathbf{m}_{\widetilde{\chi}_j^-}\mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{X}_{c_1 j}^{25}C_{ic_1}^L)$$

$$+ c_0^{32}(2\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{X}_{c_1 j}^{25}\mathcal{W}_{ic_1}^2 - 2\mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{Y}_{c_1 j}^{25}\mathcal{W}_{ic_1}^1 + (2\mathbf{m}_{H^-}^2 + \mathbf{m}_Z^2)\mathcal{Y}_{c_1 j}^{25}C_{ic_1}^R)$$

$$+ c_2^{32}(\mathbf{m}_{\widetilde{\chi}_j^-}\mathcal{X}_{c_1 j}^{25}\mathcal{W}_{ic_1}^2 + 3\mathbf{m}_{H^-}^2\mathcal{Y}_{c_1 j}^{25}C_{ic_1}^R - \mathbf{m}_{\widetilde{\chi}_i^0}\mathcal{Y}_{c_1 j}^{25}\mathcal{W}_{ic_1}^1)$$

$$f_2^{32} = f_1^{32}(L \leftrightarrow R,\ \mathcal{W}^1_{ic_1} \leftrightarrow \mathcal{W}^2_{ic_1},\ \mathcal{X}^{25}_{c_1j} \leftrightarrow \mathcal{Y}^{25}_{c_1j})$$

$$f_1^{33} = -f_1^{32}(\mathcal{T}^{32} \to \mathcal{T}^{33},\ b_0^{32} \to b_0^{33}, c^{32}_{(0,1,2)} \to c^{33}_{(0,1,2)},\ \mathcal{W}^1_{ic_1} \to \mathcal{W}^8_{in_1},\ \mathcal{W}^2_{ic_1} \to \mathcal{W}^8_{n_1i},$$

$$\mathcal{Y}^{25}_{c_1j} \to \mathcal{Y}^{26*}_{jn_1},\ \mathcal{X}^{25}_{c_1j} \to \mathcal{X}^{26*}_{jn_1}, C^L_{ic_1} \to \mathcal{X}^{1*}_{in_1},\ C^R_{ic_1} \to \mathcal{X}^1_{in_1})$$

$$f_2^{33} = f_1^{33}(\mathcal{X}^1_{in_1} \leftrightarrow \mathcal{X}^{1*}_{in_1},\ \mathcal{X}^{26*}_{jn_1} \leftrightarrow \mathcal{Y}^{26*}_{jn_1})$$

$$f_1^{34} = f_1^{33}(\mathcal{T}^{33} \to \mathcal{T}^{34},\ b_0^{33} \to b_0^{34}, c^{33}_{(0,1,2)} \to c^{34}_{(0,1,2)},\ \mathcal{X}^1_{in_1} \to \mathcal{X}^2_{in_1},\ \mathcal{X}^{1*}_{in_1} \to \mathcal{X}^{2*}_{in_1})$$

$$f_1^{34} = f_1^{33}(\mathcal{T}^{33} \to \mathcal{T}^{34},\ b_0^{33} \to b_0^{34}, c^{33}_{(0,1,2)} \to c^{34}_{(0,1,2)},\ \mathcal{X}^1_{in_1} \to \mathcal{X}^2_{in_1},\ \mathcal{X}^{1*}_{in_1} \to \mathcal{X}^{2*}_{in_1})$$

$$f_1^{35} = f_1^{34}(\mathcal{T}^{34} \to \mathcal{T}^{35},\ b_0^{34} \to b_0^{35}, c^{34}_{(0,1,2)} \to c^{35}_{(0,1,2)},\ \mathcal{X}^2_{in_1} \to \mathcal{X}^3_{in_1},\ \mathcal{X}^{2*}_{in_1} \to -\mathcal{X}^3_{in_1})$$

$$f_1^{35} = f_1^{34}(\mathcal{T}^{34} \to \mathcal{T}^{35},\ b_0^{34} \to b_0^{35}, c^{34}_{(0,1,2)} \to c^{35}_{(0,1,2)},\ \mathcal{X}^2_{in_1} \to \mathcal{X}^3_{in_1},\ \mathcal{X}^{2*}_{in_1} \to -\mathcal{X}^{3*}_{in_1})$$

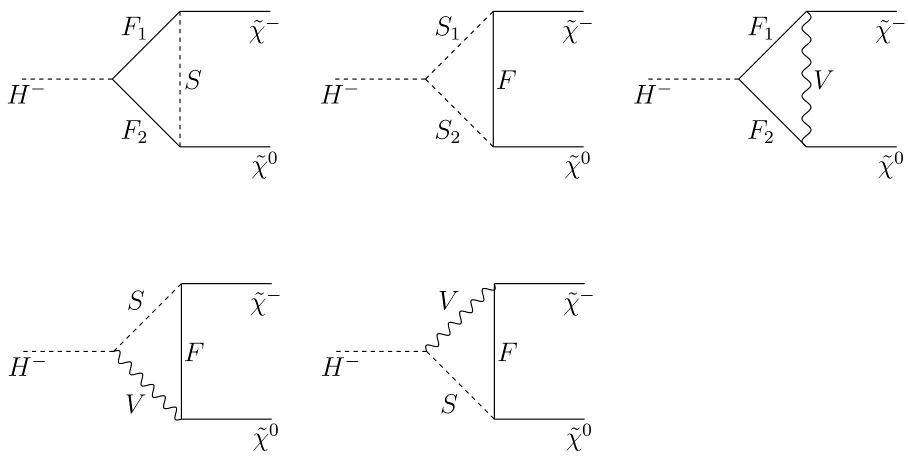

Figure 2: The vertex one-loop Feynman diagrams for $H^- \to \widetilde{\chi}^-\widetilde{\chi}^0$. F_1F_2S: $\widetilde{\chi}^0\widetilde{\chi}^-\phi^0$, $\widetilde{\chi}^-\widetilde{\chi}^0\phi^-$, $f'f\bar{f}$; S_1S_2F: $\phi^0_B H^-\widetilde{\chi}^-$, $\phi^0_T G^-\widetilde{\chi}^-$, $H^-\phi^0_B\widetilde{\chi}^0$, $G^-\phi^0_T\widetilde{\chi}^0$, $\widetilde{f}'\widetilde{f}f$; F_1F_2V: $\widetilde{\chi}^-\widetilde{\chi}^0 Z$, $\widetilde{\chi}^0\widetilde{\chi}^-W^-$; SVF: $H^-Z\widetilde{\chi}^0$, $\phi^0_T W^-\widetilde{\chi}^-$; VSF: $\gamma H^-\widetilde{\chi}^-$, $ZH^-\widetilde{\chi}^-$, $W^-\phi^0_T\widetilde{\chi}^0$. $\phi^0 = \{h^0, H^0, A^0, G^0\}$, $\phi^0_B = \{h^0, H^0\}$, $\phi^0_T = \{h^0, H^0, A^0\}$, $\phi^- = \{H^-, G^-\}$

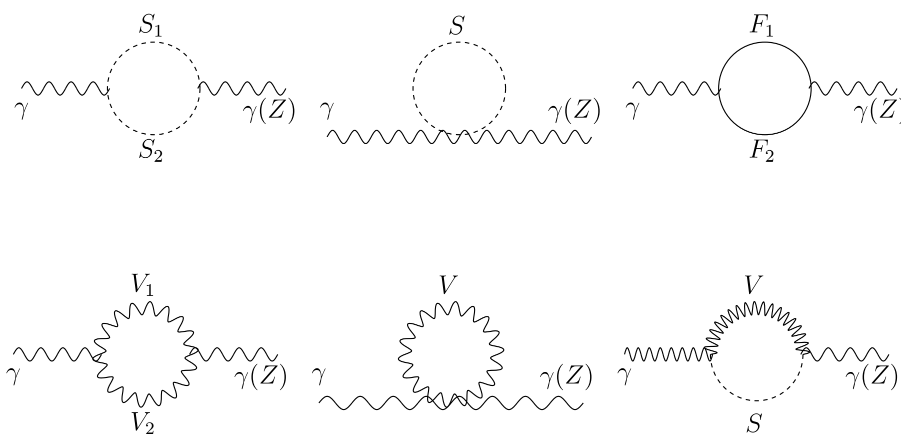

Figure 3: The $\gamma\gamma$ and γZ self-energy Feynman diagrams. S_1S_2: H^-H^+, G^-G^+, $\widetilde{e}\bar{\widetilde{e}}$, $\widetilde{u}\bar{\widetilde{u}}$, $\widetilde{d}\bar{\widetilde{d}}$; S: ϕ^-, $\widetilde{e}$, $\widetilde{u}$, $\widetilde{d}$; F_1F_2: $e\bar{e}$, $u\bar{u}$, $d\bar{d}$, $\widetilde{\chi}^-\widetilde{\chi}^+$; V_1V_2: W^-W^+; V: W^-; VS: W^-G^+, W^+G^-.

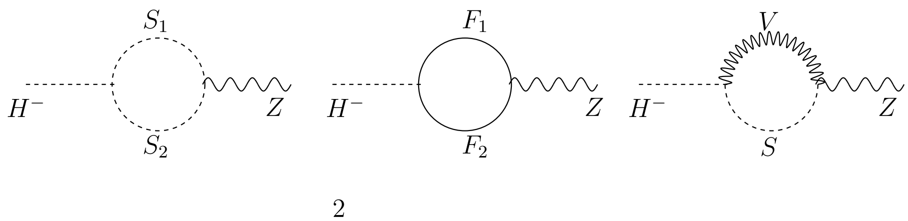

Figure 4: The H^-W^- self-energy Feynman diagrams. S_1S_2: $H^-\phi_B^0$, $G^-\phi_B^0$, $\widetilde{e}\bar{\widetilde{\nu}}$, $\widetilde{d}\bar{\widetilde{u}}$; F_1F_2: $e\bar{\nu}$, $d\bar{u}$, $\widetilde{\chi}^-\widetilde{\chi}^0$; VS: $W^-\phi_B^0$.

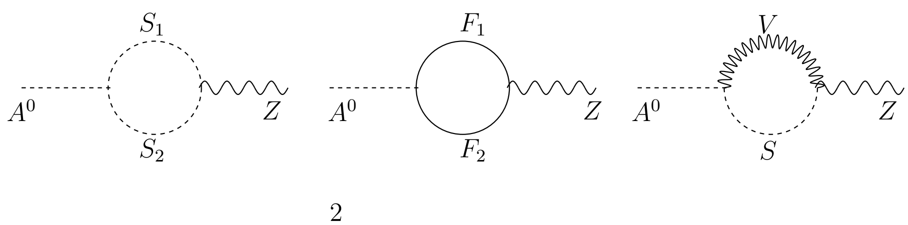

Figure 5: The A^0Z self-energy Feynman diagrams. S_1S_2: $A^0\phi_B^0$, $G^0\phi_B^0$, $\widetilde{e}\bar{\widetilde{e}}$, $\widetilde{u}\bar{\widetilde{u}}$, $\widetilde{d}\bar{\widetilde{d}}$; F_1F_2: $e\bar{e}$, $u\bar{u}, d\bar{d}$, $\widetilde{\chi}^-\widetilde{\chi}^+$, $\widetilde{\chi}^0\widetilde{\chi}^0$; VS: $Z\phi_B^0$.

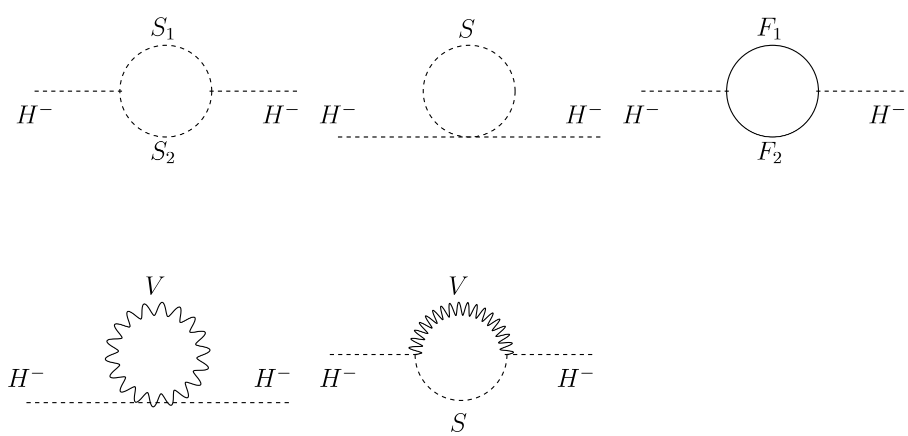

Figure 6: The H^-H^- self-energy Feynman diagrams. S_1S_2: $H^-\phi_B^0$, $G^-\phi_T^0$, $\widetilde{e}\bar{\widetilde{\nu}}$, $\widetilde{d}\bar{\widetilde{u}}$; S: ϕ^-, ϕ^0, $\widetilde{e}$, $\widetilde{\nu}$, $\widetilde{u}$, $\widetilde{d}$; F_1F_2: $e\bar{\nu}$, $d\bar{u}$, $\widetilde{\chi}^-\widetilde{\chi}^0$; V: γ, Z, W^-; VS: γH^-, ZH^-, $W^-\phi_T^0$.

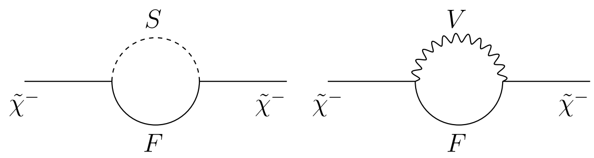

Figure 7: The $\widetilde{\chi}^-\widetilde{\chi}^-$ self-energy Feynman diagrams. SF: $\phi^0\widetilde{\chi}^-$, $\phi^-\widetilde{\chi}^0$, $\widetilde{\nu}e$, $\widetilde{e}\nu$, $\widetilde{u}d$, $\widetilde{d}u$; VF: $\gamma\widetilde{\chi}^-, Z\widetilde{\chi}^-, W^-\widetilde{\chi}^0$.

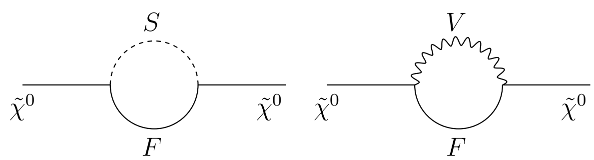

Figure 8: The $\widetilde{\chi}^0\widetilde{\chi}^0$ self-energy Feynman diagrams. SF: $\phi^0\widetilde{\chi}^0$, $\phi^-\widetilde{\chi}^+$, $\phi^+\widetilde{\chi}^-$, $\widetilde{\nu}\bar{\nu}$, $\widetilde{e}\bar{e}$, $\widetilde{u}\bar{u}$, $\widetilde{d}\bar{d}$, $\bar{\widetilde{\nu}}\nu$, $\bar{\widetilde{e}}e$, $\bar{\widetilde{u}}u$, $\bar{\widetilde{d}}d$; VF: $Z\widetilde{\chi}^0, W^-\widetilde{\chi}^+, W^+\widetilde{\chi}^-$.

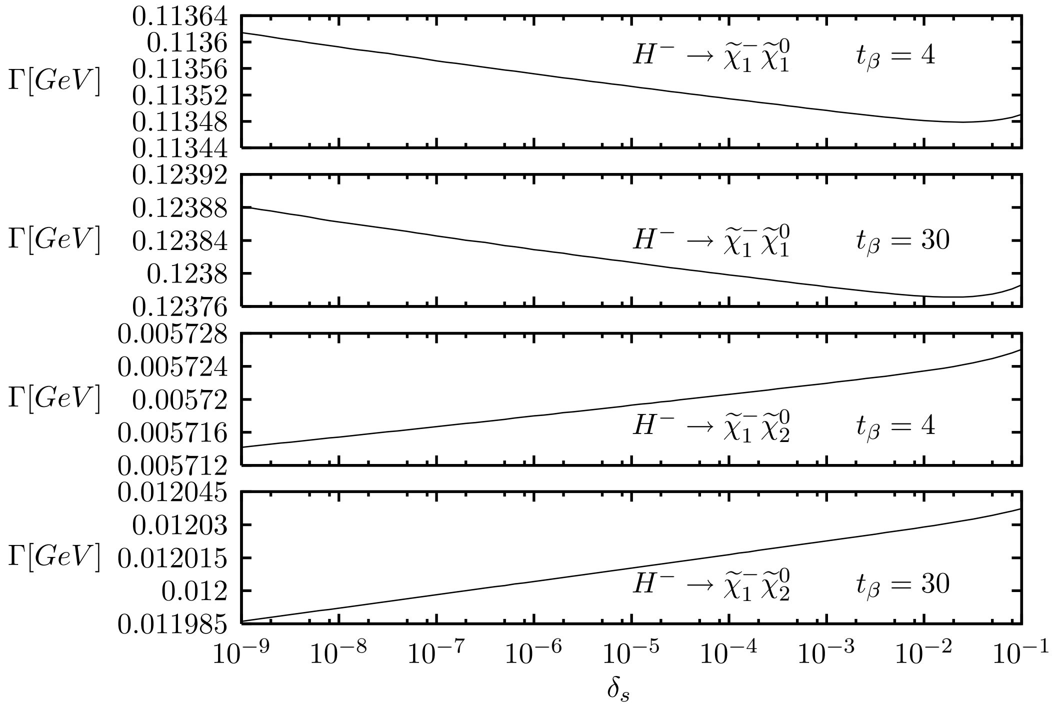

Figure 9: The dependence of the decay width on the soft photon cut-off scale.

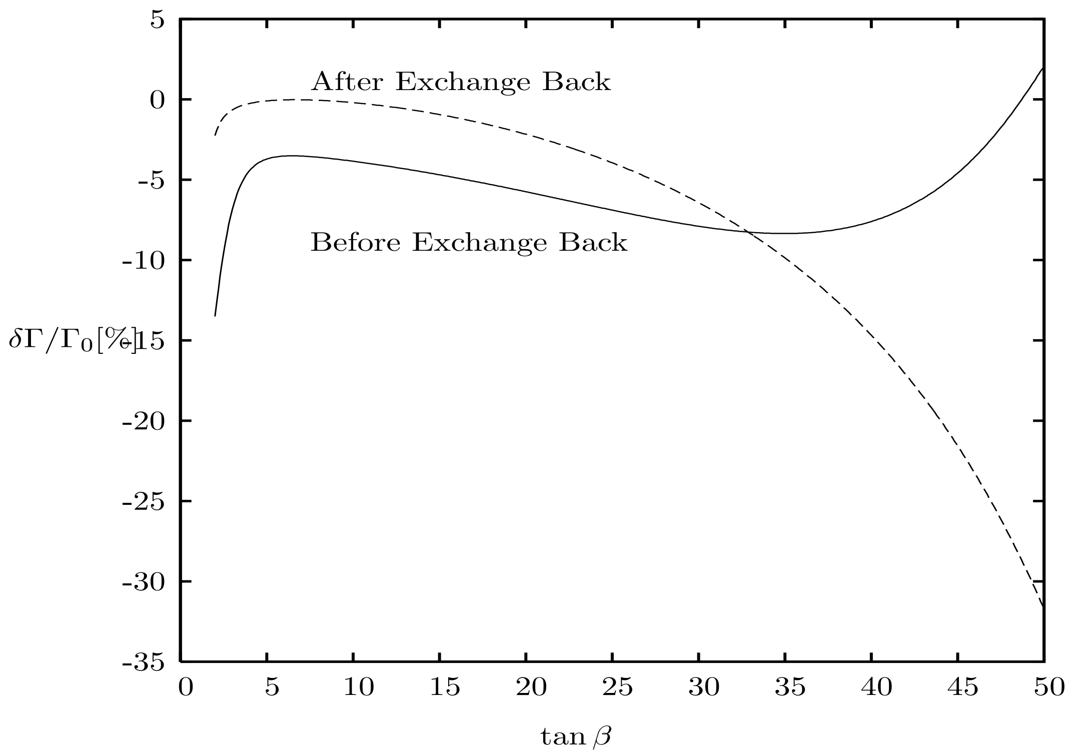

Figure 10: The LO corrections to $H^- \to \widetilde{\chi}_1^- \widetilde{\chi}_2^0$ before and after exchanging back

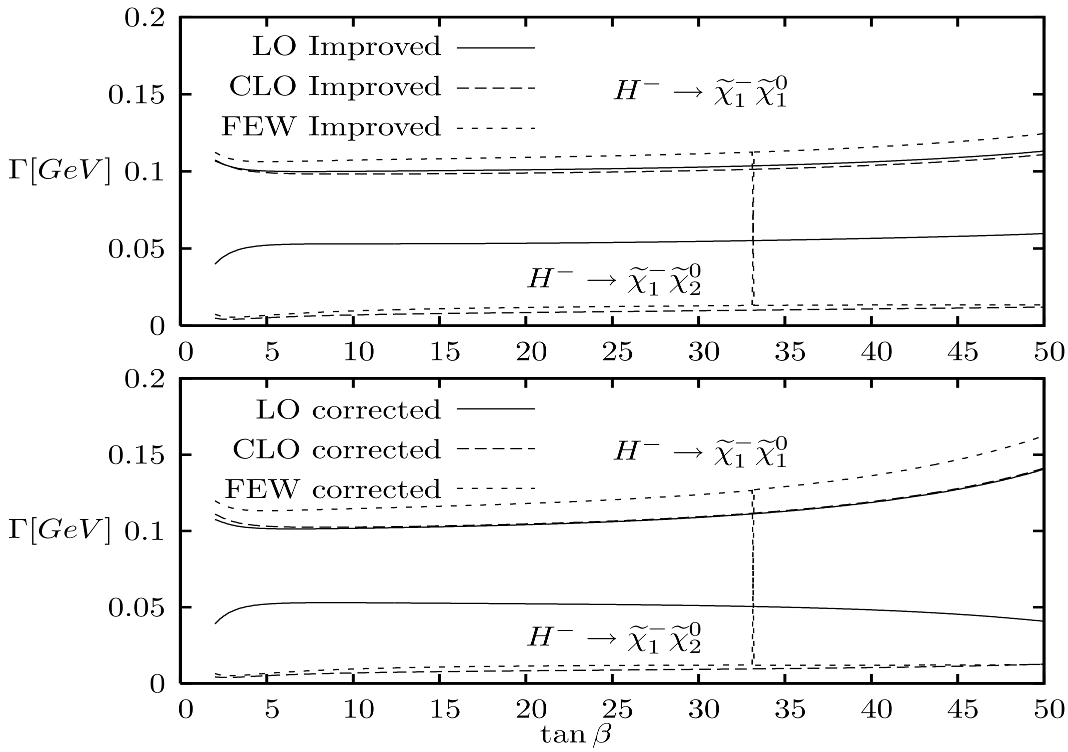

Figure 11: The improved tree-level decay width (above) and the corrected decay width (below) as the functions of $\tan\beta$.

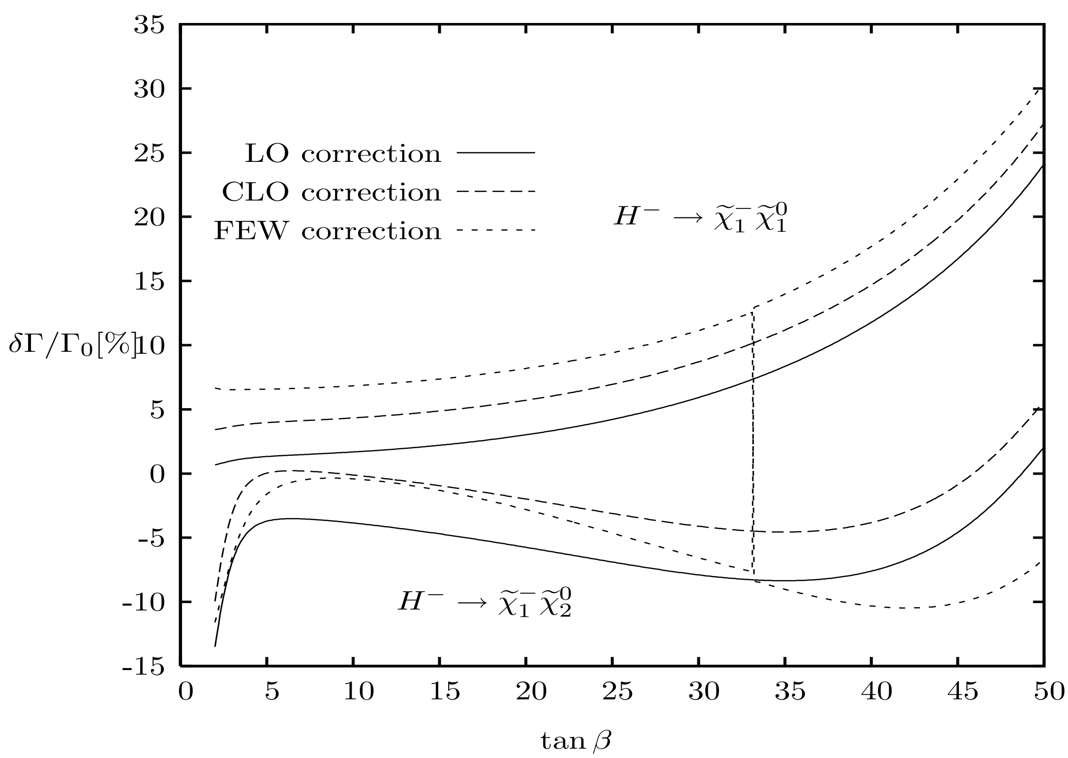

Figure 12: The relative correction as the functions of $\tan\beta$.

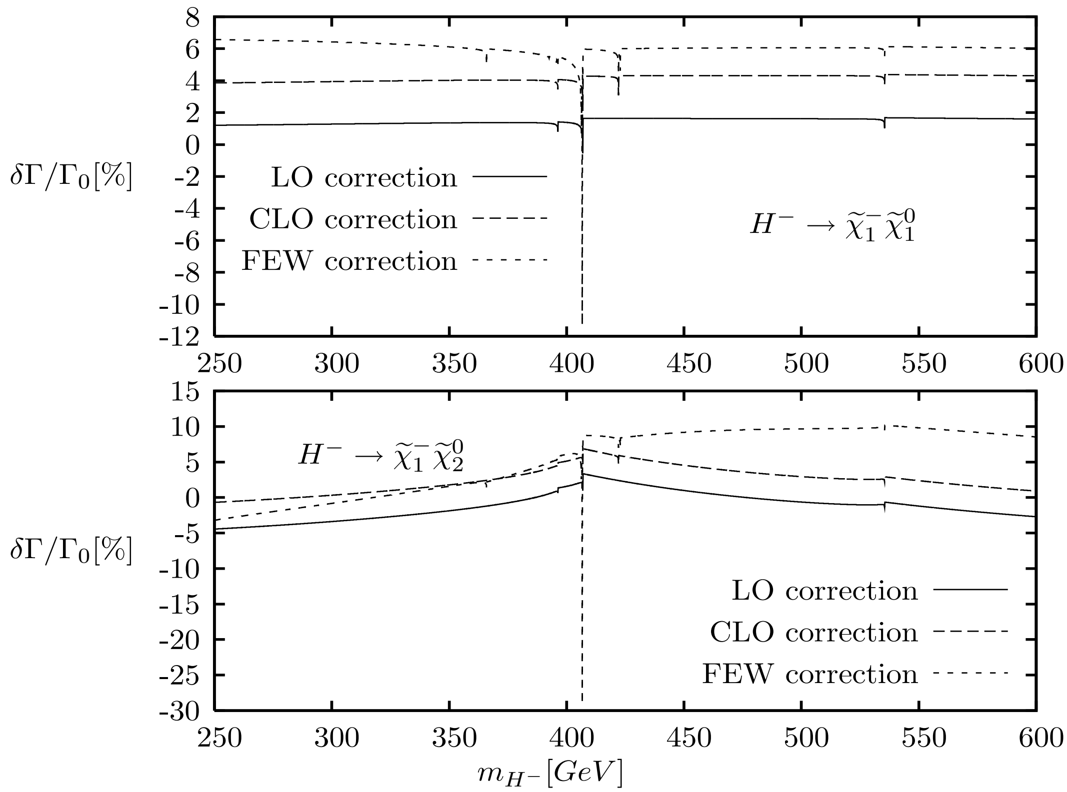

Figure 13: The relative correction as the functions of m_{H^-} for $\tan\beta = 4$.

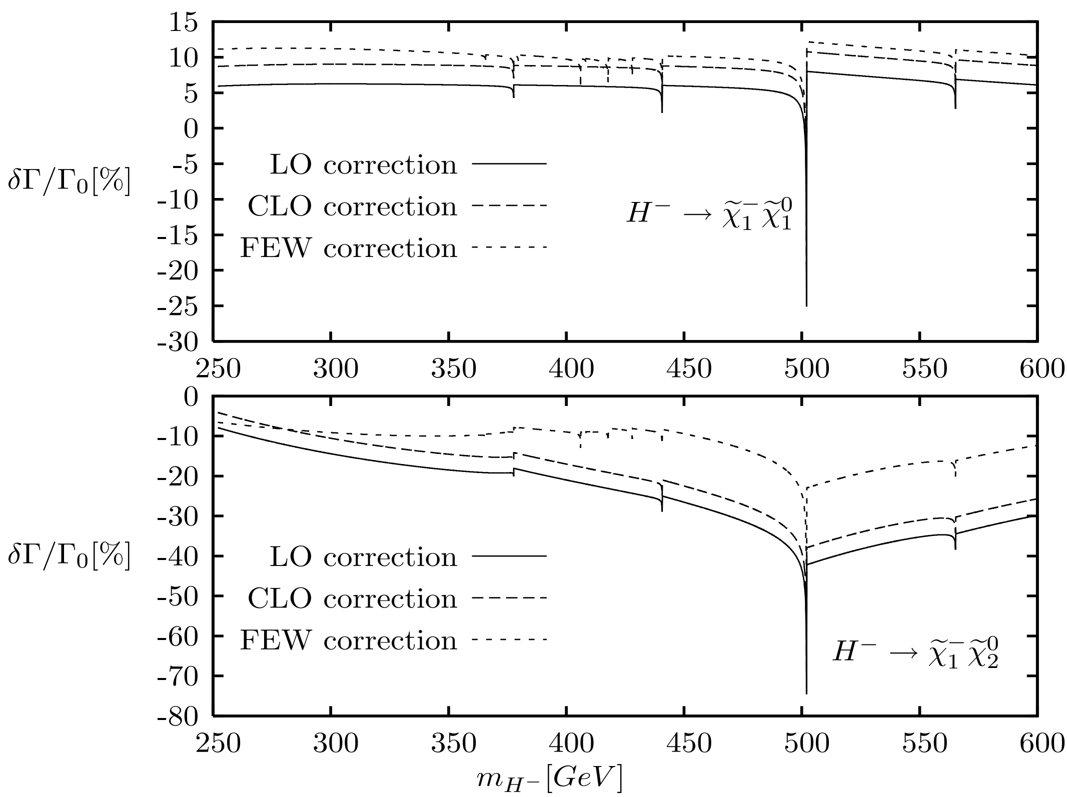

Figure 14: The relative correction as the functions of m_{H^-} for $\tan\beta = 30$.

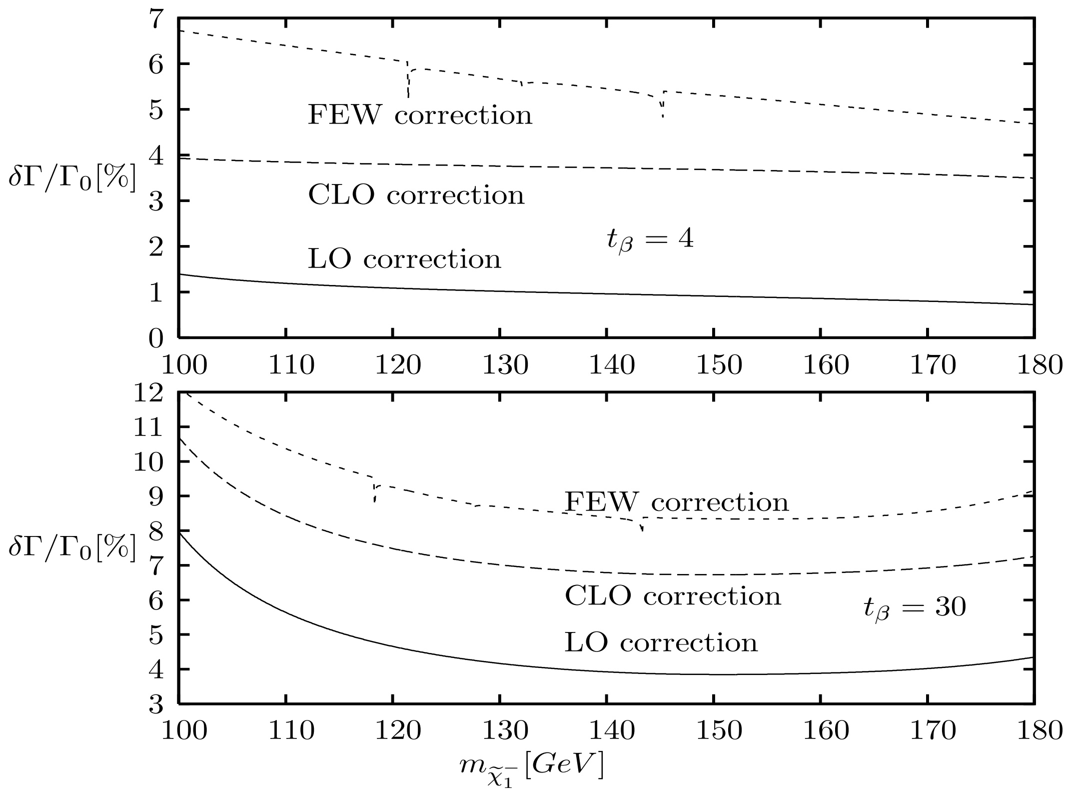

Figure 15: The relative correction as the functions of $m_{\widetilde{\chi}_1^-}$ for $H^- \to \widetilde{\chi}_1^- \widetilde{\chi}_1^0$.

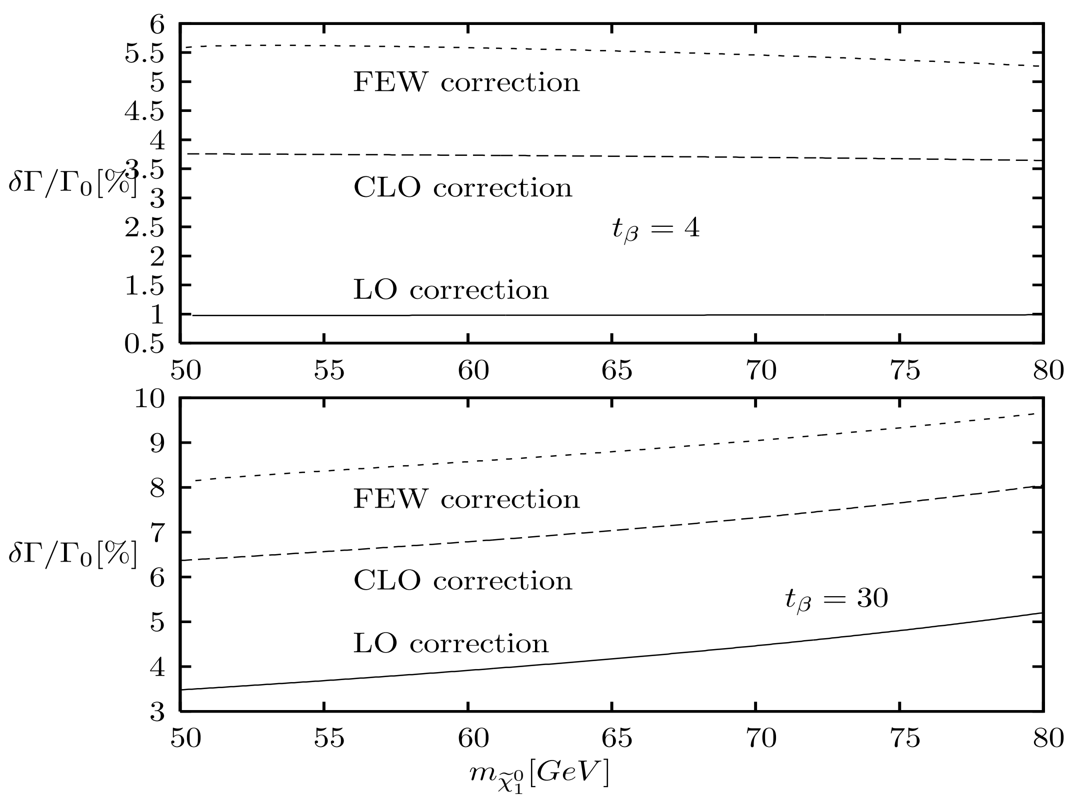

Figure 16: The relative correction as the functions of $m_{\widetilde{\chi}_1^0}$ for $H^- \to \widetilde{\chi}_1^- \widetilde{\chi}_1^0$.

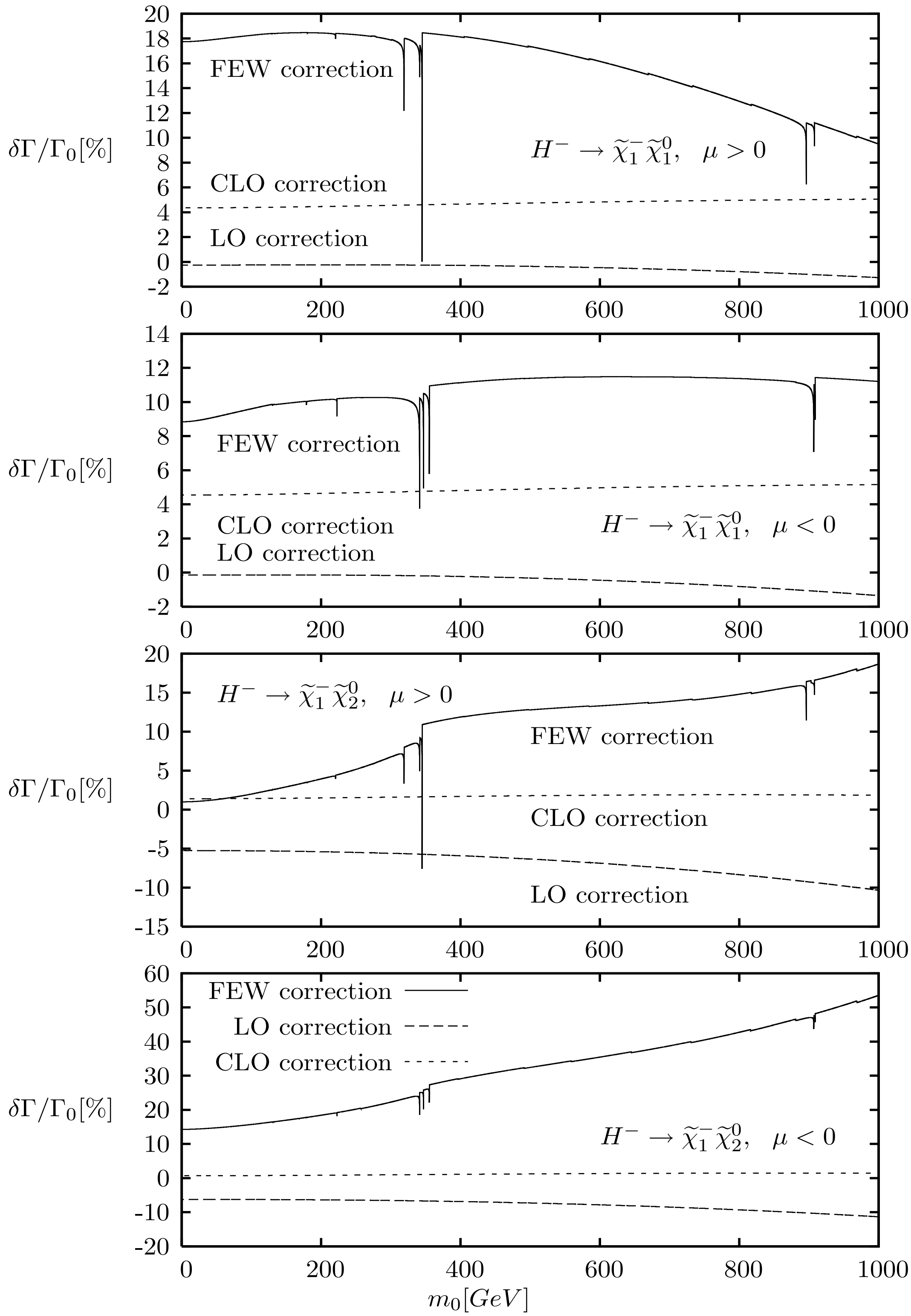

Figure 17: The relative correction as the functions of m_0.

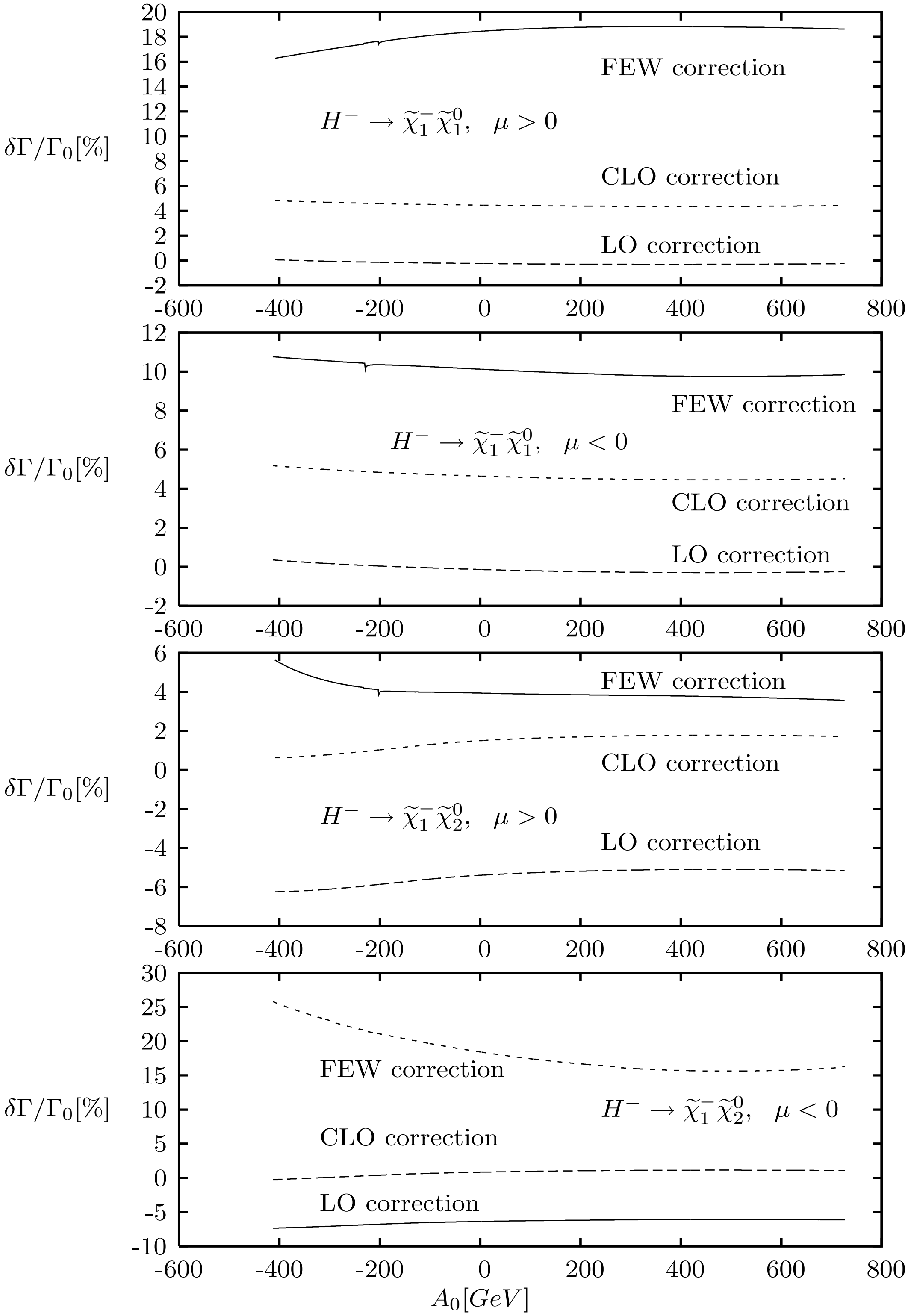

Figure 18: The relative correction as the functions of A_0.